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Stratigraphy of the Lower Ordovician Axemann Limestone in Central Pennsylvania

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Stratigraphy of the Lower Ordovician Axemann Limestone of Central Pennsylvania

By John A. Lees

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PREFACE

This report gives the results of a study to determine how the Axemann Limestone series of rock layers in central Pennsylvania were formed, what their physical and chemical properties are now, and how they may be used by industries in Pennsylvania and elsewhere.

The rocks studied consist of alternating layers of limestone and dolomite which are collectively known as the Axemann Formation. Being somewhat less resistant to erosion than many of the other rock formations which form ridges in central Pennsylvania, the rocks of the Axemann Formation are usually found in valleys. The limestone and dolomite layers are respectively composed largely of calcium carbonate and magnesium carbonate. It is the physical and chemical properties of these compounds which make these rocks of potential use to many diverse industries.

The report contains detailed descriptions of each of the types of limestone and dolomite found to occur in the Axemann Formation. The descriptions were prepared by examination of the rock in the field and by microscopic study and analyses of samples brought into the laboratory. The report also gives measurements of the thickness of the Axemann limestone and dolomite layers and shows how the thickness changes from one place to another. Descriptions of the various particles that form the rock and the fossil animals found in the rock are also included.

This report should be of particular use to mineral consuming industries, to professional geologists, to planners in the area, to highway and construction engineers, conservationists, and to students of geology and the natural history of Pennsylvania. Industries desiring specific properties of limestone and dolomite, or specific combinations of certain of the rock layers, will be able to use the data on thickness and physical-chemical properties to select potential areas for quarrying. Planners and those engaged in construction of highways and other major projects will know where the necessary raw materials are and where consideration should be given to valuable mineral-bearing property. Students of geology and natural history will better understand the events which created these rock layers in ancient seas covering Pennsylvania 500 million years ago.

The author concludes that the various types of limestone and dolomite layers in the Axemann Formation were formed in different environments of the ancient sea. The coarser grained rocks formed where currents were swift, while the finer grained rocks formed where the water was quieter. Some layers formed from particles that were chemically precipitated from the sea water. The dolomite layers formed by later chemical replacement of the limestone layers.

It is hoped that this report will stimulate greater use, effective conservation, and better understanding of a portion of Pennsylvania.

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STRATIGRAPHY OF THE LOWER ORDOVICIAN AXEMANN LIMESTONE IN CENTRAL PENNSYLVANIA

By John A. Lees

ABSTRACT

The Axemann Formation includes calcirudite, pelmatozoan calcarenite, lithic calcarenite, oolitic calcarenite, fine-grained calcarenite, calcilutite, structureless, laminated and mottled finely crystalline, medium crystalline and coarsely crystalline dolomite.

The Axemann Formation is divided into two members in the vicinity of Bellefonte and State College. The upper member, herein named the Half-Moon Hill Member, is 150 feet thick and is characterized by a predominance of calcilutite interbedded with dolomite, and the lower member, herein named the Rockview Member, is 250 feet thick and is characterized by a predominance of calcarenite interbedded with dolomite. The Rockview Member can be further subdivided on the basis of the calcarenite sublithotypes into upper calcarenite beds 80 to 100 feet thick composed of approximately equal amounts of the calcarenite sublithotypes interbedded with dolomite; pelmatozoan calcarenite beds 60 to 100 feet thick composed of pelmatozoan calcarenite and calcirudite interbedded with dolomite; and lower calcarenite beds 80 to 120 feet thick which are similar to the upper calcarenite beds. The reference section for the Axemann Limestone is the Bellefonte section located in the town of Bellefonte, Centre County, Pennsylvania.

The Half-Moon Hill Member is absent south of the Bellefonte-State College region, and has apparently graded as a facies change into the lower Bellefonte Dolomite. The Axemann Limestone south of State College is represented by rocks equivalent to the Rockview Member, and it can be traced for 50 miles to the southwest.

The Axemann Limestone is not always present along a particular line of outcrop as a limestone. The Axemann crops out in several belts of exposure which trend in a northeast-southwest direction. At four locations there is evidence which supports the hypothesis that the limestone has graded laterally into dolomite, and elsewhere where the Axemann is missing as a limestone it is presumed to disappear in the same way.

The different rock types reflect different environments of deposition. The calcirudites and coarse calcarenites reflect agitated, shallow water, open marine environments, and the fine-grained calcarenites represent quieter environments farther removed from the area of most active agitation. The pelmatozoan calcarenites accumulated in areas where salinity, oxygen content, current activity and bottom conditions favored the development of pelmatozoans, whereas the lithic calcarenites were deposited in areas less favorable for life, perhaps on mud banks. Oolitic calcarenites indicate an environment where calcium carbonate was being precipitated in warm, shallow waters, and, in some instances, perhaps where agitation was too great for the development of abundant pelmatozoans. The calcilutites reflect quiet-water environments, either in deeper water below wave base, or in shallower, re-

stricted areas. Finely crystalline dolomite probably represents shallow, restricted conditions with more than normal marine salinity where perhaps lime-mud was being altered penecontemporaneously to dolomite. Medium- and coarsely crystalline dolomite represents diagenetic replacement of coarser limestones which were originally deposited in more open marine environments.

Complex interbedding of rocks representing the different lithotypes indicates many environmental changes. Early Axemann deposition apparently occurred under warm, open marine conditions, while later deposition occurred under more quiet, restricted conditions. The western margin of deposition was probably on the shallowing border of the low, western land mass in quiet, shallow, warm, restricted waters of more than normal salinity suitable for the deposition of dolomite. This environment presumably shifted east and north in later Axemann time, permitting the accumulation of dolomite south of State College which is equivalent to the Half-Moon Hill Member of the Axemann Limestone.

Places on the eastern flank of the Nittany Arch where the Axemann is missing and has apparently been replaced by dolomite may represent shallow promontories or local, restricted highs over which all accumulated sediments were dolomitized.

INTRODUCTION

PURPOSE AND SCOPE

The Axemann Limestone of the Lower Ordovician Beekmantown Group has been mapped by Butts as a continuous unit in the vicinity of Bellefonte, Centre County, Pennsylvania, but on the other hand, in the Tyrone, Huntingdon, and Hollidaysburg quadrangles, it is shown as a discontinuous unit which apparently is missing stratigraphically from place to place. There are three possible reasons to account for this: 1) The Axemann Limestone was never deposited at some localities, 2) the Axemann was deposited widely, and later was locally eroded before deposition of the next younger rocks, and 3) the Axemann Limestone from place to place undergoes a facies change. This study is an attempt to investigate which of the above hypotheses is correct.

Additional purposes of this thesis are 1) to describe the rock types and fossils of the Axemann, 2) to learn something of the paleogeography of the area of accumulation, and 3) to review inter-regional relationships of the Axemann fauna of the Bellefonte area to faunas which have been described in Vermont, Maryland, Virginia, and the Chambersburg region of southern Pennsylvania.

Three sections are described in detail, and twenty-nine sections are illustrated in order to present lithologic features and faunal assemblages of the Axemann Limestone, and to find possible zones or horizons which can be traced from section to section on the basis of faunal and lithologic evidence.

Laboratory studies have been integrated with the fieldwork. Thus, etched sections and thin sections have been prepared and studied in order to substantiate the field classification of the rocks and to help gain information about modes of origin and paleogeographic interpretations.

GENERAL STRATIGRAPHIC POSITION OF THE AXEMANN LIMESTONE, AND AREA OF INVESTIGATION

The Axemann Formation is located stratigraphically above the Nittany Dolomite and below the Bellefonte Dolomite within the Beekmantown Group of central Pennsylvania. The Beekmantown Group is between 3000 and 4000 feet thick, and the bottom of the Axemann occurs about 1800 feet above the base of the Beekmantown (Fig. 1). The thick-

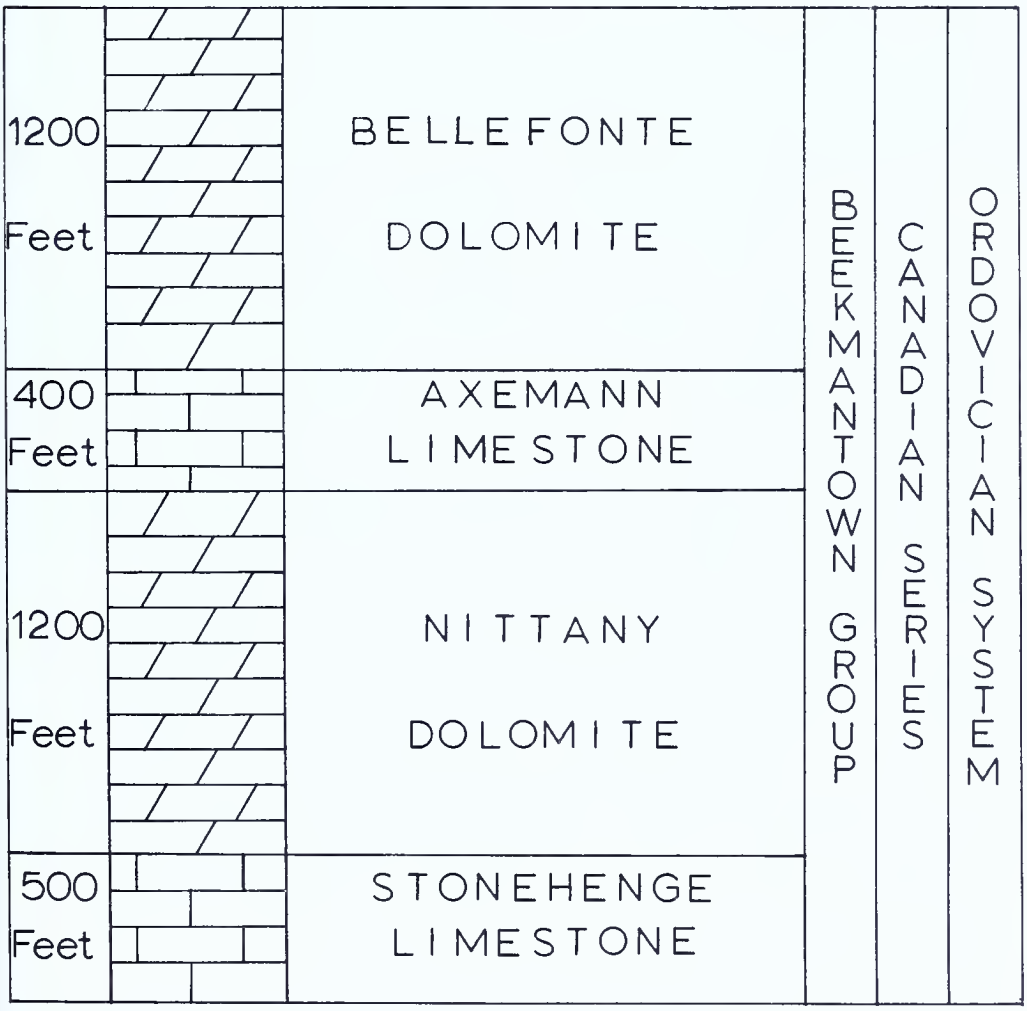

Figure. 1. Generalized columnar section of the Lower Ordovician Beekmantown Group of central Pennsylvania.

ness of the Axemann varies from about 200 feet southwest of State College, to about 400 feet near State College, to over 600 feet 10 to 15 miles southeast of State College, and over 700 feet thick 20 miles northeast of State College.

The area of investigation together with the locations of measured sections is shown in Plate 16. The area of investigation extends along the Nittany Arch from the town of Lamar, in Clinton County, southwest to the village of Waterside in Bedford County, and is about 80 miles in length and about 10 miles in width. In addition, it includes exposures along Coffee Run in Kishacoquillas Valley, 16 miles southwest of State College, in Mifflin County.

PREVIOUS WORK

Collie (1903) studied a sequence of Ordovician rocks exposed at Bellefonte and recognized various faunal zones or horizons. One of the horizons, the A-3, he described as "thick bedded crystalline limestone of dark color, stained with iron oxide, containing *Bathyurus amplimarginatus*, 157 feet." Ulrich (1911) restudied the rocks of the A-3 horizon of Collie's and named them the Axemann Limestone.

According to Butts (1936) the Axemann Limestone in the Bellefonte quadrangle consists of "layers as much as two feet thick of pure, coarsely crystalline, fossiliferous limestone interbedded with thin-layered, impure, fine-grained dolomitic limestone. The crystalline beds are partly oolitic and conglomeratic. Most of the pebbles are reddish iron-stained fragments of limestone."

In 1939 Butts described the Axemann of the Tyrone quadrangle as "very inconsistent in its outcrop, not a trace to be found for long stretches," and in 1945 he reported similar inconstancies in the Hollidaysburg-Huntingdon quadrangles.

In a petrographic study of Beekmantown rocks in the vicinity of Bellefonte and State College, Folk (1952) included information about the upper 80 feet and the lower 100 feet of the Axemann.

Macaulay (1952), in a stratigraphic report, described in detail two sections of the Axemann, one near Axemann, Pennsylvania, and the other in Kishacoquillas Valley along Coffee Run. Both of these sections are illustrated in this paper, together with the section described by Ulrich at Bellefonte. The latter section has been redescribed by the writer and included in the appendix.

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PETROGRAPHY

INTRODUCTION

A petrographic study of the Axemann Limestone based on observations of thin sections and etched sections was undertaken to aid understanding of stratigraphic relationships and modes of sedimentation. The following discussion is concerned with composition of the Axemann rocks, characteristics of the components making up the rocks, sedimentary structures, and the way in which these features permit classification of the rocks in terms of lithotypes and sublithotypes.

COMPOSITION

The field descriptions used in this paper include a visual estimate of the composition of the rock based on the reaction of the rock with acid, as well as on texture, color of both fresh and weathered surface, and mode of weathering.

The Axemann Formation consists of limestones interbedded with dolomites. The limestones effervesce freely in a 1.3 normal solution of hydrochloric acid, are quite variable as to crystallinity size and grain size not only from one bed to another but also within a single sample, and are commonly medium gray on the fresh surface and variable in color on the weathered surface. Dolomites effervesce very little, if at all, in a 1.3 normal solution of hydrochloric acid, are quite uniform in crystallinity which is commonly fine, lack a granular texture for the most part, are medium gray to medium light gray on the fresh surface, in general weather browner than calcite due to some iron content, tend to weather in relief, and have a thicker weathered zone.

COMPONENTS

In their vast bulk, the components of the rocks are made of carbonate, with the noncarbonate components being much less important. Thin section and etched section studies indicate that most of the limestones of the Axemann are composed of clastic grains, meaning, as used here,

grains which were on the surface of sedimentation.* These grains presumably were moved about by current or wave action to a greater or lesser degree. The components are arranged in certain combinations of grains, matrix, and cement. Where the clastic components occur in two distinct sizes, the larger are called grains, and the smaller matrix. When only one grain-size is apparent, the term matrix is not used, and all the clastic components are called grains. Cement is a chemical precipitate which occurs as intergranular pore fillings and as overgrowths. The major types of components are listed in Table 1.

Carbonate Components

Calcite Components. — Microcrystalline calcite or lime-mud, is composed of finely divided calcite, the particles of which cannot be resolved under the microscope, and they are assumed to be the size of fine silt or clay. The microcrystalline calcite is dark gray in color, brownish in thin section, and the color is probably due to inclusions of clay or organic matter.

Microcrystalline calcite forms rock bodies by itself, and it also forms some of the grains and matrix of coarser, clastic rocks.

* The term clastic as used by Grabau (1904) refers to grains "formed by agents acting from without upon already existing rock matter, reducing it to a finer condition either by mechanical or by chemical means, while still leaving it in a solid state." He then classified the clastic limestones according to grain-size as calcirudite, calcarenite and calcilutite. The writer has found this classification to be useful in discussing the rocks of the Axemann Limestone. However, since Grabau stipulated that this is a classification of *clastic* limestones, the writer, after conversations with Dr. F. M. Swartz of The Pennsylvania State University, feels that Grabau's above definition of the term clastic is too restricting to be practical. In too many instances examination of the components of the rocks failed to reveal whether or not they actually had been reduced to finer material. In particular, pelmatozoan plates examined by the writer usually offer no evidence of abrasion, and in many cases, perhaps most, it is impossible to tell whether sand-sized particles of lime-mud had been abraded from coarser material or built up from finer material. Lime-mud itself if derived from abrasion of coarser material would be considered clastic by Grabau, but if produced as a chemical precipitate would not be so considered. Lack of diagnostic evidence prohibits discriminaton between the two modes of formation. Since Grabau's classification is most applicable to the rocks of the Axemann Limestone, it is used to refer to rocks which are clastic in the sense that they are composed of components which are recognizable as grains which were present on the surface of sedimentation as opposed to crystalline rocks which show no granular structure. Rocks composed of lime-mud are arbitrarily considered to be clastic in this broader sense in that their texture is too fine to determine whether or not they are granular, but it is assumed that they are composed of clay-sized or very fine silt-sized particles which were grains on the surface of sedimentation. Thus the term clastic is not limited in this paper to components derived only from abrasion.

Table 1. *Major Components in Rocks of the Axemann Limestone*

Carbonate Components	Noncarbonate Components
Calcite Components	Quartz Sand
Microcrystalline Calcite	Authigenic Quartz
Pellets	Silt or Clay
Oolites	Chert
Limestone Rock Fragments	
Bioskeletal Remains	
Sparry Cement	
Dolomite Components	
Idiomorphic Dolomite	
Xenomorphic Dolomite	

Pellets are grains of microcrystalline calcite, or lime-mud, which are on the order of 0.063 millimeters in diameter. They are well rounded, spherical, structureless, and are usually uniform in size.

Limestone rock fragments are grains which are usually coarser than 0.25 millimeters, are well rounded to angular, and show high to low sphericity. They are commonly fairly well rounded, ovate to rather flat, and they are composed of lime-mud, or aggregates of pellets.

Oolites are rounded, spherical to ovate grains with a concentric and/or radial structure around a nucleus, which may be a quartz grain, lime-mud pellet, bioskeletal fragment, or dolomite rhomb.

Bioskeletal remains occur as fossils and fossil fragments, making up the bulk of some of the coarser grained rocks. Pelmatozoan plates are the most common bioskeletal material found in the rocks, and they are equidimensional to elongate, average about 0.5 millimeters in diameter, and show unit extinction. In thin section, the plates are clear to cloudy, and commonly show good cleavage. Trilobite fragments, gastropod remains, and brachiopods are less common than the pelmatozoan plates. The trilobite remains appear as long, narrow grains composed of structureless calcite, whereas the gastropod shells occur as a coarsely crystalline, sparry mosaic, apparently formed by recrystallization. Brachiopod fragments are not very common, and tend to show a wavy, fibrous structure parallel to the long dimension of the shell.

Sparry calcite occurs as pore filling, cavity filling, joint and fracture filling, and as overgrowths. Sparry calcite occurring as pore filling is usually found in the coarser grained rocks where there are large intergranular interstices and where little matrix is observed. It is commonly clear, medium- to coarsely crystalline, and occurs as a mosaic between the grains of the rock. In the fine-grained rocks, the sparry calcite is commonly finely crystalline. Overgrowths of sparry calcite are common in the coarser rocks, and in many cases are seen on pelmatozoan plates.

They are not only in optical continuity with the plates, but they also may have a cleavage developed in them which continues into the plates. Cavities, fractures, and joints filled with sparry calcite are seen in all the rock types of the Axemann.

Dolomite Components. — Dolomite components occur as fine, medium, or rarely coarse crystals, either idiomorphic, with a distinct rhombic form, or xenomorphic, without a distinct rhombic form.

Finely crystalline xenomorphic and idiomorphic dolomite occur as thin layers and discrete patches within limestone, and as thicker layers or beds interbedded with limestone. Finely crystalline idiomorphic dolomite also occurs as widely separated individual grains within a microcrystalline calcite matrix, and is occasionally seen as oolite nuclei.

Most of the medium- and coarsely crystalline dolomite occurs in beds and as patches within dolomite beds, not commonly within limestone beds. In part, it also occurs as a sparry cavity filling similar to sparry calcite. Finely crystalline dolomite is much more common within the Axemann than the medium- to coarsely crystalline dolomite.

Noncarbonate Components

Quartz sand, authigenic quartz, silt or clay, and chert are much less common than the carbonate components in that they occur as minor components within carbonate rock types and hardly ever occur as the dominant components.

Quartz sand is dominantly composed of rounded to sub-rounded spherical quartz grains about 0.5 millimeters in diameter. It is mostly associated with finely crystalline dolomite, and occurs as thin layers or as individual grains floating in a dolomitic matrix, and in rare instance as the major constituent of the rock.

Authigenic quartz is present in the Axemann as doubly terminated crystals up to 1 millimeter in length which may or may not contain a quartz sand grain as a nucleus. Where observed, authigenic quartz has been found more commonly in insoluble residue than in thin section (Pl. 6, fig. 7).

Silt or clay is disseminated through the formation at many levels as irregular anastomosing seams less than a millimeter thick and very rarely as a fine matrix in dolomite. The color of microcrystalline calcite indicates that clay may be present in this material.

Chert is not a component in exactly the same sense as the sand or silt, since it forms bodies within the limestone rather than being an integral part of the limestone itself. Most of the chert occurs as ovate nodules 1 or 2 inches in diameter, rarely 1 foot in diameter, with the long axis parallel to the bedding. Chert also occurs in part as discontinuous layers parallel to the bedding, and mostly between 0.5 and 1 inch thick (Pl. 2, fig. 2).

SEDIMENTARY STRUCTURES

Sedimentary structures of the limestones and dolomites can be divided into layered structures and nonlayered structures. The layered structures consist of laminae, bands and beds. Laminae are layers of the order of 1 millimeter thick or part of a millimeter, and are seen as alternations of different material, grain-size, or crystallinity. They manifest themselves by either an obvious color difference or by differential weathering. Silt or clay commonly occurs in thin, irregular, anastomosing, discontinuous laminae or seams on the order of 1 millimeter thick. Bands, as here described, are layers on the order of 1 or 2 centimeters thick. Usually they are bands of dolomite within a limestone, or bands of one limestone lithotype within another limestone lithotype. Less commonly they are bands of limestone within a dolomite, and rarely they are bands of quartz sand within a carbonate rock. Beds are layers which are generally greater than two inches thick. Where they are separated by partings, they are defined by the distance between the partings, and where they are welded, they are defined by the distance between one lithotype or sublithotype boundary and the next.

The nonlayered sedimentary structures include vugs and mottling. Vugs are cavities within the rock ranging up to an inch or so in diameter, and are either empty or filled with carbonate or silica. Mottling refers to the appearance of rocks which seem to be stained with different colors, or, more specifically, with different shades of the same color. Mottled rocks are quite commonly limestones mottled with dolomite, dolomite mottled with limestone, and dolomite mottled with dolomite of a different shade of color or of different crystallinity size. The mottling occurs as discrete, irregular patches to streaks more or less parallel to the bedding. These streaks, in turn, grade into irregular bands, and finally into quite regular bands. Other structures found in the rocks not related to sedimentation include pitting on the weathered surface and stylolites. Sedimentary structures are illustrated in Plates 1-3.

LITHOTYPES AND SUBLITHOTYPES

Measurements and observations in the field and laboratory have led to the recognition in the Axemann Limestone of six lithotypes and four sublithotypes based on composition, grain-size, grain-type, crystallinity, and sedimentary structures. In that the limestones are considered to be clastic rock, they are described by the terms calcirudite, calcarenite, and calcilutite (Grabau, 1904). The dolomites are classified predominantly by crystallinity and sedimentary structure since their texture usually does not indicate whether or not they are clastic. The lithotypes and sublithotypes are listed in Table 2.

Table 2. *Lithotypes and Sublithotypes of the Axemann Limestone*

Lithotypes and Sublithotypes	Definitive Features
Limestone Lithotypes	
Calcirudite	Contains some to many very coarse grains, or pebbles, greater than 5 mm.
Calcarenite	Fine- to coarse-grained.
Medium- to coarse-grained Calcarenite	Grain-size from 0.25 mm to 5 mm.
Pelmatozoan Calcarenite	Dominantly composed of pelmatozoan plates along with other bioskeletal remains.
Oolitic Calcarenite	Dominantly composed of medium-grained oolites.
Lithic Calcarenite	Dominantly composed of medium- to coarse-grained fragments of microcrystalline calcite or fine-grained calcarenite.
Fine-grained Calcarenite	Dominantly composed of pellets of microcrystalline calcite on the order of 0.063 mm in diameter.
Calcilutite	Dominantly composed of microcrystalline calcite with grains less than 0.063 mm in diameter.
Dolomite Lithotypes	
Laminated Dolomite	Finely crystalline, commonly idiomorphic dolomite, laminated with aphanitic, argillaceous dolomite.
Mottled Dolomite	Fine- to coarsely crystalline dolomite mottled with calcite or dolomite of a different color or crystallinity.
Structureless Dolomite	Fine- to very finely crystalline, homogencous dolomite.

The size terminology for both grains and crystallinity used in definitions and descriptions of lithotypes is given in Table 3 and is based on a modification of the Wentworth scale. The differences between the scale used in this paper and the Wentworth scale occur where the natural boundaries of the size of the components of the Axemann Limestone do not occur at the boundaries established in the Wentworth scale.

Distinguishing characteristics of the above lithotypes and sublithotypes are discussed below, and photomicrographs of representative thin sections are shown in Plates 4-9.

Calcirudites

The calcirudites contain pebbles that are 5 millimeters in diameter or greater, and many range up to several centimeters. Most of the large grains are composed of fine-grained calcarenite, but some are made of

microcrystalline calcite. Both types of these large grains or pebbles commonly are flat or discoidal with rounded edges, but they may be irregular, equidimensional, and angular.

The grains persistently occur in a calcarenite matrix cemented with sparry calcite. The matrix may be either fine-, medium-, or coarse-grained rock fragments, oolites, pellets, or bioskeletal fragments, and it may be composed of one or a combination of any of these grain-types. The occurrence of microcrystalline calcite in the matrix is rare.

The calcirudites do not dominate any one portion of the section, but, more often than not, they occur as layers and thin beds within thicker sequences of calcarenite, and less commonly calcilutite.

Calcarenites

The calcarenites are divided into four sublithotypes based on the characteristics of the grains. The sublithotypes include pelmatozoan calcarenites, oolitic calcarenites, lithic calcarenites, and fine-grained calcarenites.

Pelmatozoan Calcarenites. — Pelmatozoan calcarenites are composed predominantly of pelmatozoan plates, and lesser amounts of gastropod, trilobite and brachiopod remains together with some sand-sized carbonate rock fragments and pellets. The intergranular pore spaces are filled with sparry calcite, and microcrystalline calcite rarely occurs as a matrix. The pelmatozoan plates break with good cleavage surfaces which readily reflect light, and this reflection of light from the plates is an easily observable and diagnostic characteristic for field identification.

Table 3. *Terminology for Grain-Size and Crystallinity-Size*

Grain-Size	*Size in mm*	*Crystallinity-Size*
Very Coarse-Grained	5 mm or greater	Very Coarsely Crystalline
Coarse-Grained	0.5 - 5 mm	Coarsely Crystalline
Medium-Grained	0.25 - 0.5 mm	Medium-Crystalline
Fine-Grained	0.125 - 0.25 mm	
	0.063 - 0.125 mm	Finely Crystalline
Very Fine-Grained	0.015 - 0.063 mm	Very Finely Crystalline
	Less than 0.015 mm	Aphanitic

Oolitic Calcarenites. — Oolitic calcarenite consists of oolites, commonly 0.125 millimeters to 0.5 millimeters in diameter, although they may be as large as 1 millimeter in diameter, cemented with sparry calcite. Fossil remains, rock fragments, and pellets commonly, though not necessarily, are associated with these rocks, and microcrystalline calcite as a lime-mud matrix is rare.

Lithic Calcarenites. — The lithic calcarenites are generally medium- to coarse-grained and are composed of fragments of calcilutite or fine-grained calcarenite. The shape of the grains ranges from well rounded, spherical grains to angular, irregular fragments, and the grains occur in a sparry cement with or, more commonly, without a lime-mud matrix. Lesser amounts of bioskeletal and oolitic material may be associated with these rocks.

Fine-Grained Calcarenites. — The fine-grained calcarenites are composed dominantly of rounded, spherical to ovate, well-sorted pellets of microcrystalline calcite about 0.063 millimeters in diameter, and they are cemented with sparry calcite. Sometimes they are seen to occur with a lime-mud matrix, and less commonly there is finely divided bioskeletal material associated with the pellets. In thin section the fine-grained calcarenites are often seen to consist of layers of more densely packed pellets separated by layers containing fewer pellets and a higher percentage of sparry cement. The layering appears as laminations and cross-laminations. In the field the fine-grained calcarenites resemble rocks made of microcrystalline calcite in that the grains are not visible, but the sparry cement gives the whole rock a finely crystalline appearance, and the broken surface is usually not as conchoidal, nor as smooth as the surfaces of rocks made of microcrystalline calcite. The color on the fresh surface is dark gray.

Calcilutites

The calcilutites mostly are dark gray, aphanitic limestones that break with a smooth, conchoidal fracture, and are composed dominantly of microcrystalline calcite. In the field they are seen to form whole beds, or they occur as thin layers within other rock types. They commonly contain some calcarenite grains, and if they contain much of this material, they are called calcarenitic calcilutites. Stylolites, irregular seams, and dolomitic banding and mottling are apparent in many of these rocks, and fossils are rather rare, with the exception of gastropods which are not uncommon in them.

In thin section, they are grayish to brownish in color, presumably because of included clay or organic material, and their constituent grains, unable to be resolved under the microscope, are assumed to be of fine silt or clay size. Individual idiomorphic dolomite rhombs are abundant in many of the calcilutites.

Laminated Dolomite

The laminated dolomites are a fairly uniform group of rocks. For the most part they are medium gray on the fresh surface and weather a yellowish or olive gray, are finely crystalline, consist of grains of dolomite 0.015 millimeters to 0.125 millimeters in diameter, and many of the grains are idiomorphic. The laminae consist of alternating layers of finely crystalline dolomite and aphanitic dolomite, and the aphanitic dolomite probably contains a high percentage of silt and clay-size quartz since it is dark brownish in color, often weathers in relief, and when the laminated dolomites are dissolved in hydrochloric acid, they yield a high percentage of insoluble material. Quartz sand is found in many of these rocks as bands and laminae, as well as individual grains, widely separated, and floating in the dolomite matrix.

Mottled Dolomite

The mottled dolomites range in crystallinity from fine to coarse, and their color is more variable than the laminated dolomites, ranging from light to dark. The mottling occurs as patches or streaks of material of a different color or crystallinity from that of the surrounding rock, and may be streaks or patches of calcite within a dolomite, patches or streaks of dolomite of a different crystallinity from that of the surrounding dolomite, or may occur as dolomitized ghosts of what may have been previously clastic grains. The individual crystals may be either idiomorphic or xenomorphic.

Structureless Dolomite

The structureless dolomites are light colored, show a uniform, homogeneous texture of fine to very fine crystallinity, and are commonly idiomorphic. They may occur as beds of dolomite showing no laminations, banding or mottling, but they occur more commonly as bands and mottles themselves within limestones, particularly calcilutite. In volume, they are the least abundant of the dolomite lithotypes.

STRATIGRAPHY

INTRODUCTION

Ulrich (1911) named the Axemann Limestone from an exposure at Bellefonte, although he took the name from the village of Axemann one mile to the southeast, near which the Axemann also is exposed. Ulrich's section in Bellefonte is located on the eastern side of South Water Street and begins near the intersection of South Water Street and High Street.

He described 158 feet of limestone and dolomite directly above exposed Nittany Dolomite and below a concealed interval several hundreds of feet thick which is overlain by Bellefonte Dolomite. His description of this unit is as follows: "Thick and thin bedded, nearly pure limestone, dark in color, frequently stained with iron oxide and ranging in texture from compact to distinctly crystalline." The writer remeasured and described in detail the above section, and the description is given in the appendix. By projecting the top of these rocks 1000 feet to the southwest, and by continuing the traverse through a 100-foot concealed interval, an additional 126 feet of limestone are found just below the Axemann - Bellefonte contact, establishing the thickness of the Axemann Limestone at Bellefonte as approximately 400 feet.

Additional sections of the formation have been investigated between Bellefonte and State College, and since the Axemann Limestone displays uniform characteristics at all of these places, it will be considered as a unit through the Bellefonte - State College region. On the other hand, outside of this area, and farther to the northeast, southeast and southwest, the formation changes, and will therefore be discussed under the separate headings The Lamar - Axemann - Coffee Run Region and The State College - Waterside Region.

THE BELLEFONTE - STATE COLLEGE REGION

Eight sections were measured and described in the vicinity of Bellefonte, Axemann, Rockview and State College. The Axemann Limestone in this region is about 400 feet thick, and can be divided into two members on the basis of the occurrence and distribution of rocks of the types previously described. The upper member is characterized by a dominance of calcilutite and is named the Half-Moon Hill Member for its exposure in a road cut one half mile southeast of the village of Coleville in the side of Half-Moon Hill. The lower member is characterized by a dominance of calcarenite and is named the Rockview Member for its exposure in a quarry at the Rockview Penitentiary.

The Half-Moon Hill Member

The Half-Moon Hill Member is exposed at all sections in the area except at the Rockview section and, except for a few feet of rock at the Benner Pike section. The best exposures of the member are near Bellefonte, Coleville, and Rupp Quarry, State College. The contact between the two members is nowhere well exposed, but the best estimate of the thickness of the Half-Moon Hill Member, obtained near Axemann, is of the order of 150 feet.

The Bellefonte section and the Half-Moon Hill section near Coleville expose the upper 125 feet of the Half-Moon Hill Member. In both sections the upper contact with the Bellefonte Dolomite is visible. Directly above the contact, 60 feet of Bellefonte Dolomite are present at Bellefonte, and 180 feet at Coleville. About 60 percent of the Bellefonte section is limestone and 40 percent dolomite, rather regularly distributed through the sequence. One-quarter of a mile to the southwest at the Half-Moon Hill section 85 percent is limestone and 15 percent is dolomite.

The limestone dominantly is an aphanitic, dark-gray calcilutite which weathers light gray, and is 1- to 2-foot bedded, though some beds are 0.5 foot thick. Distributed through the sequence are thin beds of pelmatozoan calcarenite and lithic calcarenite, and some of the calcilutites have pelmatozoan plates or lithic grains floating in a lime-mud matrix. Both types of calcarenites are in beds 2 to 3 inches thick, and are more common towards the base of the exposed part of the member. Much of the calcilutite is laced with irregular, anastomosing, silty seams, and it is mottled and banded with dolomite. In many places the dolomitic mottling is seen to grade across bedding from irregular mottling into sub-parallel mottling, and then into dolomitic bands until finally whole beds are dolomite. (See Plate 1, fig. 3) The dolomite then may grade back into limestone banded with dolomite and then into limestone mottled with dolomite.

About half the dolomite is laminated and half mottled, and very little structureless dolomite is present. At Bellefonte, the laminated dolomite is confined to the upper half, but there are some laminated dolomites towards the base of the member in other sections. For the most part, the dolomite is finely crystalline, medium gray, weathers yellowish gray, and is 1- to 2-foot bedded. It is fairly evenly distributed through the section in units from 1 to 5 feet thick except at Bellefonte where a 21-foot unit of dolomite occurs at about the middle of the member. This unit is not present to the southwest in the Half-Moon Hill section.

Chert occurs in the Half-Moon Hill Member at all sections, except the Slab Cabin Creek section. It occurs in the middle of the member and towards the base in part as thin, discontinuous beds 0.5 to 1 inch thick, but more generally as nodules commonly several inches in diameter, but ranging up to 1 foot in greatest dimension along bedding. There is abundant chert float in the concealed intervals at Axemann.

The Half-Moon Hill Member is sparsely fossiliferous with a few gastropods, chiefly *Maclurites affinis* and *Hormotoma* sp. being visible on the weathered surface. Rarely, fossils are profuse in a few thin layers. Thus, high spired gastropods, probably *Hormotoma* sp., are concentrated in a

1-foot bed 50 feet above the base of the member at Axemann. Algal beds several feet thick occur a few feet below the top at the Bellefonte section and at the Axemann section. At Rupp Quarry, just below the Bellefonte Dolomite, is a 6-inch layer of pelmatozoan calcarenite in which straight cephalopods and *Ceratopea ankylosa* were found.

Three miles southwest of State College near Bloomsdorf, there is an interval 400 to 500 feet thick which is mostly concealed, but does have rare exposures of calcilutite in the upper half, which indicates the presence here of the Half-Moon Hill Member. South of Bloomsdorf, the member is missing as a limestone, and probably has undergone a facies change so that it has graded laterally into the lower part of the Bellefonte Dolomite.

Above the Axemann Limestone at the Axemann section are 500 feet of discontinuously exposed Bellefonte Dolomite. Three hundred forty feet above its base, this dolomite contains about 20 feet of dark-gray, light weathering, aphanitic calcilutite, and there are several more layers 1 to 2 feet thick below this. These limestones in the Bellefonte Dolomite may be tongues from the upper beds of the Axemann Limestone where it is more thickly developed to the northeast at Lamar and to the southeast at Coffee Run.

The Rockview Member

The Rockview Member is well exposed at all the sections studied in the Bellefonte - State College region except at the Rupp Quarry section where it is concealed. Again, in that the contact between the two members is so poorly exposed, the exact thickness of the member is not known, but is estimated at about 250 feet. The Rockview Member can be subdivided into upper and lower calcarenite beds separated by a middle unit of pelmatozoan beds.

The upper calcarenite beds, commonly in 3-inch to 1-foot layers, are 80 to 100 feet thick, and are composed of interlayered pelmatozoan calcarenite, lithic calcarenite and fine-grained calcarenite, interspersed with lesser amounts of calcilutite and dolomite. There is a 10- to 12-foot oolitic sequence at the base. The upper calcarenite beds are 75 to 85 percent limestone, and representatives of the various lithotypes are more or less equally distributed throughout the sequence except for the oolites which are concentrated at the base.

The pelmatozoan calcarenite beds, commonly in 1- to 2-foot layers, are 60 to 70 feet thick except at the Benner Pike section where they are about 100 feet thick. They consist of 50 to 60 percent pelmatozoan calcarenite with some calcirudite and minor amounts of calcilutite, together

with about 40 to 50 percent laminated and mottled dolomite. The limestones and dolomites alternate rather regularly in units about 2 to 7 feet thick. Near the base at the Rockview section there is a 14-foot dolomite unit. Some chert nodules and bands occur in the pelmatozoan beds at the Rockview section, and some of the dolomites in these beds at Rockview and elsewhere contain sparse to abundant quartz sand.

The lower calcarenites vary from 80 to 120 feet in thickness, the thickest sequence being found at the Axemann section. The amount of dolomite decreases from about 35 percent at Bellefonte to 10 percent at Axemann, and then increases to 20 or 25 percent near State College. The limestones consist of rocks of the calcarenite sublithotypes together with calcilutite, interbedded with dolomite. Some of the dolomites, especially at Rockview, contain quartz sand either concentrated in bands, or occurring as individual grains dispersed in a dolomite matrix. There is a zone about 10 feet thick occurring in the middle of the lower calcarenites which is interlayered with oolitic beds. The limestones are commonly 3-inch to 1-foot bedded, and the dolomites are 1- to 2-foot bedded.

Fossils are much more abundant and diversified in the Rockview Member than in the Half-Moon Hill Member. The species represented include gastropods, trilobites, brachiopods, and less commonly, ostracods and rare cephalopods.

The most characteristic fossil of the Axemann is the gastropod *Maclurites affinis*. This fossil has been useful to previous workers as well as to the writer in distinguishing the Axemann Limestone from the other limestones in the area since it has been found only in the Axemann, and it ranges vertically through the entire formation. High spired gastropods of the genus *Hormotoma* also are found through most of the Axemann. Aside from these, and perhaps a few other unidentified gastropods, the rest of the fossils have been found only in part of the Rockview Member.

Fossils collected from the Rockview Member are characterized by gastropods of the genus *Ophileta* and *Turritoma*, together with the trilobites *Bathyurellus* sp. 1, and *Isotelloides* sp. A few examples of the genus *Hystricurus* found at Axemann and Rockview occur in the upper half of the zone, and *Bathyurellus* sp. 2 occurs in the middle of the zone near the top of the pelmatozoan beds. The brachiopod *Tritoechia cf. T. pennsylvanica* ranges through the zone.

Rare cephalopod siphuncles, together with *Ceratopea tennesseensis*, were found at the top of the Rockview Member at the Rockview section in the upper calcarenite beds. Sub-spherical algal masses of concentric laminae 0.5 to 1 inch in diameter surrounding fossil nuclei, are found at the top of the pelmatozoan beds.

THE STATE COLLEGE - WATERSIDE REGION

The Axemann Limestone can be traced along the Nittany Arch from the Bellefonte - State College region for a distance of 50 miles through the vicinity of Baileyville to exposures near the town of Waterside. Through the region from Baileyville to Waterside, the Axemann as a limestone formation is represented only by beds which correspond to the Rockview Member of the Bellefonte - State College region, and the Half-Moon Hill Member has disappeared. As in the Rockview Member of the Bellefonte - State College region, the Axemann of the State College - Waterside region can be subdivided into three units based on calcarenite sublithotypes. The divisions can be seen clearly in certain sections, but in other sections they are less obvious. Furthermore, the formation is not persistant as a limestone along certain belts of outcrop, and at places apparently is replaced by dolomite beds which then are attributed to the Bellefonte and Nittany formations, since it is difficult to distinguish most of the Axemann equivalent dolomites from the Bellefonte Dolomite and Nittany Dolomite.

The three calcarenite units are quite similar to those of the Rockview Member, although the thicknesses are more variable. The upper calcarenite beds are composed of fine-grained calcarenite interbedded with coarse-grained lithic calcarenite, dolomite, and lesser amounts of calcilutite and pelmatozoan calcarenite. The base of this unit is not as consistently oolitic as it is in the Bellefonte - State College region. The upper calcarenite beds range from about 75 feet thick to 120 feet thick.

The middle, pelmatozoan beds are composed of pelmatozoan calcarenite and calcirudite interbedded with dolomite. The thickness of this unit and its stratigraphic position within the sequence are quite varied, most likely as a result of interfingering with the upper and lower calcarenite beds. Its thickness ranges from a few feet to 60 or 70 feet.

The lower calcarenite beds consist largely of fine- and coarse-grained lithic calcarenite interbedded with dolomite. There are minor amounts of calcilutite and rare pelmatozoan beds, except where pelmatozoan beds occur as tongues of the more thickly developed pelmatozoan unit. Except for the northernmost part of the area, the lower calcarenites contain sandy beds, usually dolomitic, which occur at or near the Axemann - Nittany contact. The thickness of the unit varies from about 100 to 140 feet, and this thickness, along with the thickness of the upper calcarenite beds, depends to a great extent upon the position and thickness of the pelmatozoan beds.

Superposed upon the general features outlined above, there are many changes in detail of sequence and thickness. South of Bloomsdorf, near State College, the Axemann is concealed for a distance of 4 miles to the village of Baileyville. At Baileyville it again is observed as a 200- to 250-

foot interval of very poorly exposed calcarenite, banded with calcilutite and dolomite. The Half-Moon Hill Member appears to be absent here, and most likely has been replaced by the lower part of the Bellefonte Dolomite. About 3 miles south of Baileyville, near Graysville, the absence of the Half-Moon Hill Member is definitely established at section No. 12.

The pelmatozoan beds in the northern part of the area near Graysville are thinly developed, but they thicken to the south, attaining a maximum thickness near Spruce Creek and Mt. Etna. (See Pl. 14) South of Mt. Etna they thin as a wedge beneath higher occurring pelmatozoan beds of Shelleytown. The pelmatozoan beds of Shelleytown in turn, thin to the north and become a tongue in the upper calcarenites above the more thickly developed pelmatozoan beds of Mt. Etna, and they also thin to the south and finally disappear. Pelmatozoan beds in the extreme south near Woodbury thin to the north and disappear beneath the higher occurring pelmatozoan beds of Shelleytown. (See Pl. 15)

At the Evergreen Farm section, about 13 miles southwest of State College, the Axemann Limestone is exposed along a hillside and in a road cut just southeast of Route No. 45, and can be divided into the same three calcarenite units that are found to the north in the Rockview Member. The section is 165 feet thick, and the upper contact with the Bellefonte Dolomite is concealed.

The rocks of the upper division are 50 feet thick and they consist of 1-foot bedded, fine-grained calcarenites interbedded with about 20 percent dolomite. Underlying this unit, pelmatozoan beds occur in an interval 22 feet thick. These are coarse-grained pelmatozoan calcarenites and calcirudites in beds 4 to 6 inches thick. The lower calcarenite beds are 110 feet thick, consist of coarse- and fine-grained, lithic calcarenite, interbedded with dolomite, and contain a 10-foot unit of pelmatozoan calcarenite in the middle. This unit of pelmatozoan calcarenite, along with the upper 22-foot unit of pelmatozoan beds, may be tongues of more thickly developed pelmatozoan beds which occur about 7 miles to the south near Spruce Creek, where they are 60 to 70 feet thick. Seven miles south of Spruce Creek, at Mt. Etna, the pelmatozoan beds are also found to be 60 to 70 feet thick, but at this section, a 14-foot unit of pelmatozoan beds occurs in the upper calcarenites. This unit may be a tongue of pelmatozoan beds which occur higher than normal in the sequence in a section 9 miles to the south near Shelleytown. The pelmatozoan beds at Shelleytown are about 60 feet thick, and are about 50 feet higher in the section than at Mt. Etna. The lower calcarenites near Shelleytown have thickened to 140 feet because of the higher occurrence of the pelmatozoan beds, and contain a 10-foot unit of pelmatozoan calcarenite which may represent a tongue of the pelmatozoan beds of

Spruce Creek and Mt. Etna. This tongue apparently disappears between Shelleytown and Beavertown 1.5 miles to the south. The pelmatozoan beds above this tongue, however, are found at Beavertown to be about 50 feet thick, and these beds disappear between Beavertown and Curreyville 10 miles farther south, although a thin unit of pelmatozoan beds at Curreyville may be a remnant of this unit. In the southernmost part of the area, near Woodbury, the pelmatozoan beds are 40 to 50 feet thick, and occur lower in the section than the pelmatozoan beds of Shelleytown and Beavertown 15 miles to the north. These beds are traced north through Curreyville, and they disappear between Curreyville and Beavertown, although there may be a remnant of them in the lower calcarenites of Beavertown.

The brachiopod *Tritoechia cf. T. pennsylvanica* occurs in the pelmatozoan beds of this region, and is frequently found in zones of abundance about one foot thick near the base of the pelmatozoan unit. However, at Shelleytown, where the pelmatozoan beds are developed higher in the sequence, it is not found at the base of this unit, but is found in the thin pelmatozoan unit within the lower calcarenite which correlates with the base of the pelmatozoan unit near Spruce Creek, where *T. cf. T. pennsylvanica* is also found. The same relationship holds at the Evergreen Farm section where *T. cf. T. pennsylvanica* is found in the lower tongue of pelmatozoan beds which correspond to the lower pelmatozoan beds near Spruce Creek which contain *T. cf. T. pennsylvanica,* and again it is found in the lower tongue of pelmatozoan beds near Curryville, which corresponds to the pelmatozoan beds to the south near Woodbury where *T. cf. T. pennsylvanica* occurs in a zone of abundance.

As was previously stated, the thickness of the upper and lower calcarenite beds in general varies according to the position and thickness of the pelmatozoan beds. Otherwise, the characteristics of these units are much the same as in their counterparts in the Bellefonte - State College region with a few exceptions. The oolites at the base of the upper calcarenite beds are rather persistant through the Bellefonte - State College region, and appear to be absent only in the extreme south at the Slab Cabin Creek section. In the State College - Waterside region, the oolites are well developed at Mt. Etna, Shelleytown, and Beavertown. They are poorly developed near Graysville, and are absent near Spruce Creek and in the extreme south near Woodbury.

The lower calcarenites contain a number of very sandy beds throughout the region from Graysville to Waterside. The sand occurs either just above the Axemann - Nittany contact, at the contact, or just below the contact, and is useful for correlation and boundary distinction. Near Graysville, there is an extremely sandy dolomite which actually occurs in the Nittany Dolomite about 28 feet below the Axemann - Nittany

boundary, and aids local correlation from section No. 10 near Graysville through section No. 13, the Evergreen Farm section. South of here, near Spruce Creek, there are sandy beds developed in the middle of the lower calcarenite beds which can be traced south from Spruce Creek to Waterside. South of Shelleytown, near Beavertown and Waterside, the above mentioned sands occur at about the base of the Axemann. At Waterside there are two thin limestone beds present below the sand in a sequence of very coarsely crystalline and coarse-grained dolomite.

The Axemann Formation appears to be thinning from about 240 feet at Mt. Etna to 180 feet at Woodbury, but about 1 mile south of Woodbury at Waterside it is about 270 feet thick. This section, however, has a 170-foot concealed interval in the middle, and there could be considerable error in the calculation of its thickness over a rather long traverse. It is also possible that the section is faulted.

The fossil occurrences in the Axemann Limestone from State College to Waterside are much the same as the occurrences in the Rockview Member of the Bellefonte - State College region. However, *Tritoechia cf. T. pennsylvanica* tends to occur in zones of abundance a foot or so thick near the bottom of the pelmatozoan beds, rather than occurring only as isolated specimens ranging over most of the Rockview Member as in the Bellefonte - State College region. Examples of *Bathyurellus* sp. 2 found near Spruce Creek show that the range of this fossil extends over most of the Axemann Limestone of the State College - Waterside region, whereas in the Bellefonte - State College region, it is found only at the top of the pelmatozoan beds of the Rockview Member.

Areas of Disappearance of the Axemann Limestone in the State College - Waterside Region

Butts mapped five areas south of State College where he shows the Axemann to be missing as a limestone. The writer has examined these areas and concurs with this finding. It appears that at the places where the Axemann is missing as a limestone it is represented by beds of a dolomitic facies. These five areas extend southwest of State College and are distributed along the flanks of the Nittany Arch. The first three areas are located on the southeast flank, and the last two are located on the northwest flank. (See Pl. 16)

The first such area is about 12 to 14 miles south of State College between Graysville and Baileyville. The second begins 19 miles south of State College, and runs for a distance of about 6 miles between Spruce Creek and a point just north of Mt. Etna. The third area begins about 22 miles south of State College, and runs for a distance of 6 miles from a point just south of Mt. Etna, past Williamsburg, to the village of Shel-

leytown. The fourth section occurs about 45 miles south of State College, 2.5 miles south of the village of Roaring Spring, and the fifth begins about 8 miles west-southwest of State College, and continues in a more southerly direction along a sinuous belt of outcrop 30 miles past Tyrone, and terminates near the village of Spruce Creek. These areas are designated (1) The Graysville Area, (2) The Spruce Creek Area, (3) The Williamsburg Area, (4) The Roaring Spring Area, and (5) The Tyrone Area.

The Graysville Area. — For much of its 2 miles south of Baileyville, the Axemann apparently is absent, and plausibly is represented by a dolomite facies which grades back into limestone south of the village of Graysville. The facies change south of Graysville can be seen in a series of four sections (Pl. 14, secs 10, 11, 12, 13 and Pl. 16) which lie along a northeast-southwest traverse 1 mile long, extending from about 0.25 mile southwest of Graysville, and running in a southwesterly direction along Route No. 45. The southernmost section on this traverse is the previously described Evergreen Farm section (No. 13) which exposes 165 feet of Axemann Limestone. Twenty-eight feet below the Axemann-Nittany contact is a two-foot interval of very sandy dolomite which can be traced to all four sections on this traverse, and is useful in correlating these sections. In section No. 12, 0.5 mile northeast of the Evergreen Farm section, the dolomite developed above the sand has thickened from the 28 feet at the Evergreen Farm section to 50 feet, and there are thick dolomites developed in the middle of the section. Both upper and lower contacts are visible, and the Axemann is about 200 feet thick. A zone of abundant *Tritoechia cf. T. pennsylvanica* occurs 60 feet above the sandstone and 10 feet above the base of the Axemann Limestone.

One-half mile northeast of Section No. 12, at Section No. 11, the dolomite above the sandy zone is 56 feet thick, and above this is an interval 30 feet thick of limestone, calcarenite above and calcilutite below, interbedded with 50 percent dolomite. The upper 40 feet of the section consist of medium-crystalline, mottled dolomite, and above this, the section is concealed. A zone of abundant *Tritoechia cf. T. pennsylvanica* occurs in the dolomites 40 feet above the sandy zone at the base of the section. The dolomites of this zone may represent part of the limestone in which *T. cf. T. pennsylvanica* was found 0.5 mile to the south, and may, therefore, represent a dolomitic facies of the lower limestones to the south.

The 2-foot sandy beds of the Nittany dolomite are again seen 400 feet to the northwest, above which is an interval 115 feet thick of scattered dolomitic outcrop and dolomitic float. There is no indication of limestone. Above this are 20 feet of medium-crystalline, granular dolomite, overlain by an interval 100 feet thick of scattered dolomitic exposures and dolomitic float. Limestone appears to be completely missing at this section, and does not appear again until Baileyville.

The Spruce Creek Area. — A belt of outcrop extends from just north of the village of Spruce Creek, where it is truncated by the Waterside fault, for a distance of about 25 miles to the south where it is truncated by the East Henrietta fault. The northern 6 miles of this belt of outcrop exposes no limestone, but dolomite does occur at the position at which the Axemann Limestone would be expected to be found. This is seen specifically near the village of Goodman, Section No. 15. South of Goodman, at Mt. Etna, the Axemann is present as a limestone. No evidence has been found to suggest a facies change in either the northern or southern part of this 6-mile segment.

The Williamsburg Area. — The belt of outcrop in the Williamsburg area is a continuation of that of the Spruce Creek area. In the Williamsburg area, the Axemann is gone as a limestone from a point just south of Mt. Etna for a distance of 6 miles to a point north of the village of Shelleytown.

One mile southwest of Mt. Etna a dolomite section was measured at a position at which the Axemann might be expected to occur (Section No. 18), and in this dolomite a zone of abundant *Tritoechia* sp. was found. In that *Tritoechia* has only been reported as occurring in the Axemann Formation or in rocks equivalent to the Axemann (Sando, personal communication), and since the section in which these fossils occur appears to be at about the same position as the Axemann Limestone, their occurrence suggests that the rocks in which they are found represents a dolomitic facies of the Axemann Limestone.

The hypothesis that these dolomites are Axemann equivalent is further strengthened by the finding of a specimen of *Ceratopea buttsi* 200 feet above the *Tritoechia* zone. *C. buttsi* has been reported only from rocks equivalent to the uppermost Axemann or lowermost Bellefonte. (Yochelson, personal communication). If the occurrence of *C. buttsi* is correlated with the upper Axemann or lower Bellefonte of the Bellefonte - State College region where the Axemann Limestone is 400 feet thick, then the *Tritoechia* zone of Section No. 18 would be equivalent to the top of the Rockview Member of the Bellefonte - State College region, or the top of the Axemann Formation of the State College - Waterside region where the Axemann is 200 feet thick. But if the occurrence of *C. buttsi* is correlated with the upper Axemann or lower Bellefonte rocks of the State College - Waterside region, then the *Tritoechia* zone would occur in rocks equivalent to the lower Axemann.

The Roaring Spring Area. — Forty-five miles southwest of State College, the Axemann disappears as a limestone just south of the town of Roaring Spring. Two miles south of Roaring Spring the Axemann outcrops along Halter Creek in a poorly exposed interval about 200 feet thick. Here the Axemann can be seen to grade laterally to the south from a lime-

stone to a dolomite in a series of four sections over a distance of about 0.3 mile. (See Pl. 17) In the northernmost section along the traverse, at about the Axemann - Nittany contact, there occurs oolitic chert in the float, and slightly higher in the sequence, extremely sandy, dolomitic float is found. The sandy and oolitic float can be traced south through the two middle sections, and into bedrock at the base of the southernmost section, Section No. 27. The amount of limestone above the sandy zone decreases from north to south along the traverse, although the interval between the upper limestone and the sandy zone at the base seems to remain constant. The limestone has disappeared at the southernmost section, Section No. 27, and the entire sequence here is dolomite. An example of *Ceratopea tennesseensis* was collected from the dolomitic rocks of this section 15 feet above the sandy zone. This fossil also is found at the top of the Rockview Member at the Rockview section in the Bellefonte - State College region. Its occurrence in the dolomites, along with the disappearance of the limestone suggests a facies change. Many of the dolomites in the southernmost section which occur at the stratigraphic position of the limestone immediately to the north are dark and very coarsely crystalline, and resemble in texture the coarsely crystalline pelmatozoan limestone of the Axemann. These coarsely crystalline dolomites may very well represent dolomitized pelmatozoan beds.

The Tyrone Area. — The Axemann is missing along a belt of outcrop about 30 miles long which runs along the northwest flank of the Nittany Arch from a point about 1 mile northwest of Spruce Creek, past Tyrone, to a point 6 miles southwest of State College. At Ironville, an exposure reveals extremely coarse dolomites at a position where the Axemann might be expected to occur, and they may be dolomitized pelmatozoan rocks, but the section was not measured because it is very severely faulted. However, Spelman (1964) reported an occurrence of *Tritoechia* sp. near Union Furnace near the Bellefonte - Nittany contact. Since *Tritoechia* has been reported only from Axemann equivalent rocks, it may be that these beds are Axemann equivalent.

THE LAMAR - AXEMANN - COFFEE RUN REGION

The Axemann Limestone thickens northeast and southeast of the Bellefonte - State College region. This thickening can be seen 16 miles southeast of State College at the Coffee Run section, which was measured and described by Macaulay (1952), and at the Lamar section, located near the town of Lamar, 22 miles northeast of State College. At the Lamar section, the Axemann is over 700 feet thick, and at the Coffee Run section it is about 600 feet thick. Thirty-five miles northeast of State College, in Clinton County, a thickness of 1200 feet for the Axemann Limestone is reported from drilling data (Wagner, 1963).

At Axemann there is about 450 feet of Bellefonte Dolomite exposed above the Bellefonte - Axemann contact. About 300 feet above this contact there is a unit of very dense aphanitic calcilutite 20 feet thick, and there are a few thin beds of calcilutite in the dolomites below this. Sixteen miles southeast of Axemann, the Axemann Limestone crops out in Kishacoquillas Valley along Coffee Run. The Axemann Limestone here is about 550 to 600 feet thick, as measured by the writer. The upper 280 feet are predominantly calcilutite interbedded with dolomite, and are considered to be equivalent to the Half-Moon Hill Member of the Bellefonte - State College region. Overlying these rocks is the Bellefonte Dolomite with a 20-foot unit of very dense aphanitic calcilutite between 120 feet and 140 feet above the base. This calcilutite may be equivalent to that seen in the Bellefonte at the Axemann exposures. (See Pl. 18)

Below the Half-Moon Hill Member are about 300 feet of rock equivalent to the Rockview Member. The upper 120 feet are pelmatozoan calcarenites interbedded with dolomites and the lower 90 feet are calcilutites, dolomites, and lithic calcarenites, together with minor amounts of pelmatozoan calcarenites. These two units correspond to the pelmatozoan beds and the lower calcarenite beds near Bellefonte, and are here separated by an 80-foot concealed interval, thus the exact thickness of each unit cannot be determined. *Maclurites affinis, Hormotoma* sp., *Ophileta cf. O. solida, Isoteloides* sp., *Bathyurellus* sp. 1, and *Tritoechia* sp. are found in the lower half of the pelmatozoan beds 220 feet above the base of the formation.

It appears that at Coffee Run, relative to the Bellefonte - State College region, the Half-Moon Hill Member has increased in thickness from 150 feet to 280 feet, and the Rockview Member has increased from 250 feet to 300 feet. Within the Rockview Member, the upper calcarenite beds are apparently missing while the pelmatozoan calcarenite beds and perhaps the lower calcarenite beds have increased in thickness. The lower contact with the Nittany Dolomite is not exposed.

The Axemann Limestone is also very thick 23 miles northeast of Coffee Run near Lamar, where a thickness of 760 feet was obtained. Here, the upper contact with the Bellefonte Dolomite is concealed, and the lower 530 feet are mostly concealed, but there are rare exposures of calcarenite which permit an approximation to the thickness. The uppermost exposed rocks of the section consist of 80 feet of calcilutite interbedded with dolomite, underlain by 40 feet of dolomite. Below the dolomite is an interval 80 feet thick, about half exposed, consisting of calcarenite, pelmatozoan above and lithic below, interbedded with dolomite. Below this unit is the 530-foot interval which is mostly concealed. Underlying the last exposed limestone of this interval, the rocks are entirely concealed, but there is abundant dolomitic and cherty float with no evidence

of limestone. This concealed portion is assumed to be the Nittany Dolomite.

The calcilutite beds in the Bellefonte Dolomite at Coffee Run may project as tongues into the lower Bellefonte Dolomite near Axemann, and also into the upper calcilutite beds above the 40-foot dolomite unit at Lamar. (See Pl. 18) However, since the upper rocks of the Axemann Limestone at Lamar are concealed, and the lower calcarenite beds are so very thick and so poorly exposed, it may well be that the calcilutite beds at Lamar correlate with the Half-Moon Hill Member at Axemann, and the Axemann Limestone near Lamar is actually thickening at the expense of the Nittany Dolomite.

The thickening of the Axemann Limestone to the northeast is further corroborated by a reported thickness of 1200 feet for the Axemann near Williamsport. This information was obtained by Wagner (1963) from the Walizer Well in Clinton County, about 35 miles northeast of State College.

REGIONAL CORRELATION

A number of the fossils restricted to the Axemann Limestone in central Pennsylvania are known to occur in middle Beekmantown rocks elsewhere in Vermont, southern Pennsylvania, West Virginia, Maryland and Virginia, and thus provide at least tentative correlation. Nevertheless, the stratigraphic ranges of some of the fossils are not well understood, and correlation of the rocks is hampered further since lithologic facies relationships are complex.

Following is a list of fossils found in the Axemann Limestone in central Pennsylvania that are more important for the purpose of correlation.

Brachiopods
- *Diparalasma cf. D. elegantulum* (Butts)
- *Tritoechia cf. T. pennsylvanica* Ulrich and Cooper

Gastropods
- *Maclurites affinis* (Billings)
- *Ophileta cf. O. solida* Butts
- *Hormotoma cf. H. gracilens* (Whitfield)
- *Turritoma cf. T. acrea* (Billings)
- *Ceratopea ankylosa* Cullison
- *Ceratopea tennesseensis* Oder

Trilobites
- *Isoteloides* sp.
- *Bathyurellus* sp. 1
- *Bathyurellus* sp. 2

In west central Vermont, at Shoreham, Brainerd and Seely (1890) described a sequence of Beekmantown rocks to which Cady (1945) assigned the following formational names: the lowermost unit is the Shelburne Formation, 295 feet, followed by the Cutting Dolomite, 350 feet, the Bascom Limestone, 375 feet, and the Bridport Dolomite, 470 feet. The total thickness of the section is 1525 feet. At the top of the Cutting Dolomite, and at the base of the Bascom Limestone is found *Lecanospira compacta*. Two hundred feet above *L. compacta* in the Bascom Limestone occurs *Maclurites affinis* and the trilobites *Hystricurus conicus* and *Isoteloides whitfieldi*. *I. whitfieldi* appears to be closely related to *I.* sp. of the Axemann Limestone. At Ft. Cassin, Vermont, Cushing (1905) included the Bridport Dolomite and the upper 200 feet of the Bascom Limestone in the Cassin Formation. Whittington (1953, pl. 68, figs. 30, 32.) illustrated a trilobite form from the Cassin Formation which strongly resembles *Bathyurellus* sp. 1 of the Axemann Limestone. In central Pennsylvania *Lecanospira compacta* is found in the Nittany Dolomite in a zone about 200 feet thick the top of which occurs in the middle of the Nittany 600 feet below the Axemann - Nittany contact, and *Maclurites affinis* ranges through the Axemann. Despite the fact that in Vermont *Lecanospira compacta* is found 200 feet below occurrences of *Maclurites affinis,* whereas in central Pennsylvania it is found 600 feet below *M. affinis,* the occurrence of *M. affinis* above *Lecanospira compacta* and the association of somewhat similar trilobites with *M. affinis* in both areas, suggests that the Bascom Limestone and the Axemann Limestone in part may be equivalent.

Bassler (1919) reported a thickness of about 2400 feet for Beekmantown sediments in Maryland. The lower 600 feet belong to the Stonehenge Limestone which has been traced through central Pennsylvania. The overlying 1800 feet are undifferentiated limestones which contain three faunal zones. The lower of these zones named the *Cryptozoon steeli* zone, is about 600 feet thick and contains *Maclurites affinis, Lecanospira ("Ophileta") compacta* and *Hystricurus* sp. The next zone, or *Ceratopea* zone, is 250 feet thick and contains *Ceratopea* sp., *Hormotoma artemesia, Maclurites sordidus,* and *"Goniurus" caudatus* which may be closely related to *Bathyurellus* sp. of the Axemann Limestone. The next division is the *Turritoma* zone which is 575 feet thick, and contains *Turritoma* sp., *Hormotoma* sp., and *Maclurites oceanus.* It appears, therefore, that 1400 feet of rock above the Stonehenge Limestone contain fossil faunas generally similar to those found in the Axemann.

Sando (1957) restudied the Beekmantown of Maryland, and believes that it is about 3600 feet thick, instead of 2400 as reported by Bassler. Above the Stonehenge Limestone is the Rockdale Run Formation which is about 2400 feet thick and contains several fossil zones. Two hundred

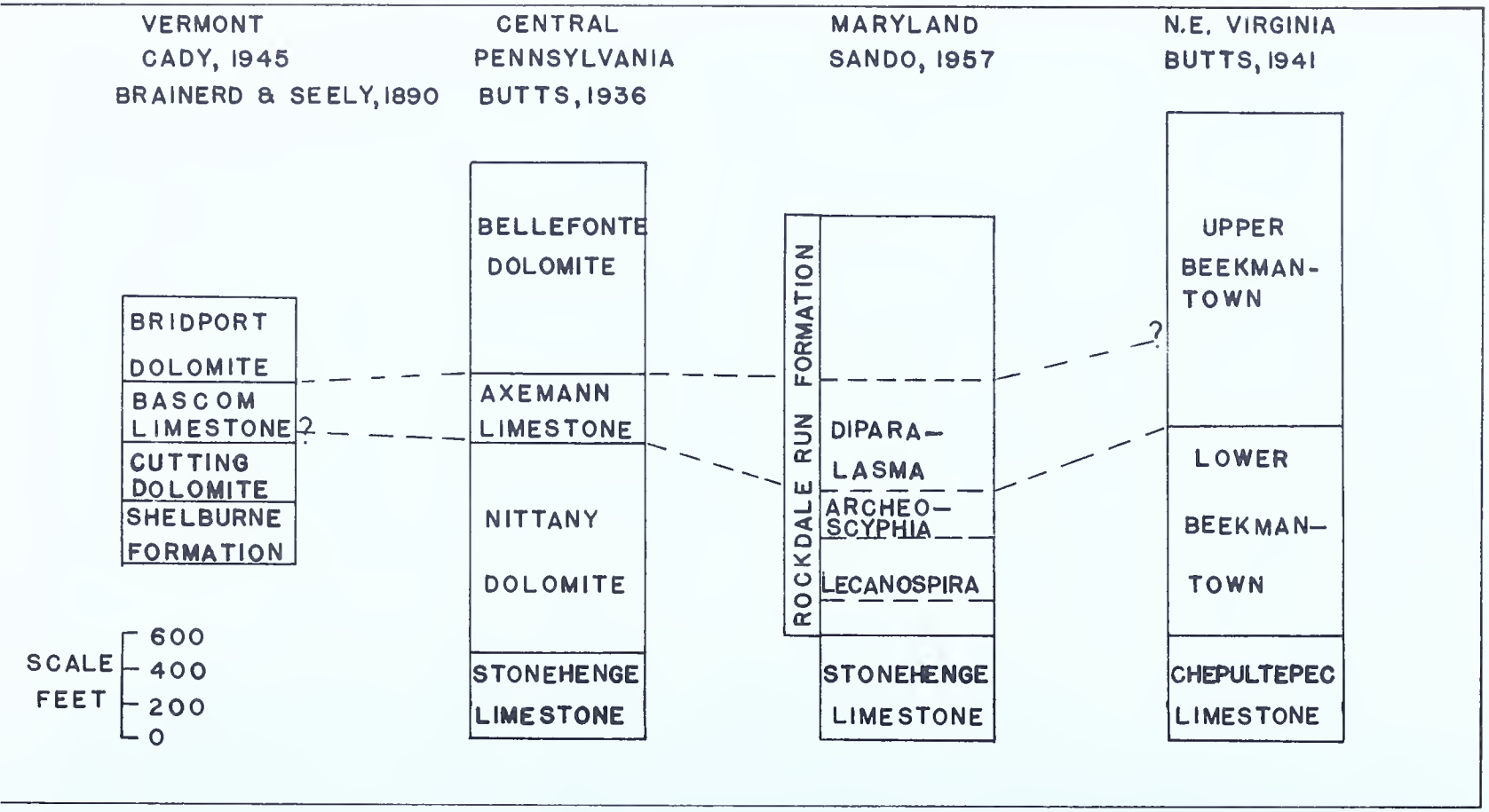

Figure 2. Tentative correlation of the Axemann Limestone with rocks in Vermont, Maryland, and Virginia.

feet above the base of the Rockdale Run is the *Lecanospira* zone which is 360 feet thick. This contains *Lecanospira compacta* and *Hystricurus* sp. Next, above this is the 230-foot *Archaeosyphia* zone. The two zones together approximate the *Cryptozoon steeli* zone of Bassler, and probably are equivalent to the Nittany Dolomite of central Pennsylvania. Above the *Archaeosyphia* zone is the *Diparalasma* zone which is 630 feet thick. This zone contains *Diparalasma* sp., *Tritoechia* sp., *Ceratopea* sp., and a species referred to *Lesueurilla* which may be the same as the form commonly identified as *Maclurites affinis.* The *Diparalasma* zone apparently overlaps much of both the *Ceratopea* zone and the *Turritoma* zone of Bassler, and is considered here as well as by Sando to be equivalent to the Axemann Limestone in central Pennsylvania. Species of *Tritoechia* have been found in central Pennsylvania almost exclusively in the Axemann Limestone, or in rocks believed to be equivalent to the Axemann Limestone. *Diparalasma elegantulum* at places occurs with *Tritoechia cf. T. pennsylvanica.* Species of *Ceratopea* have been found in the Bellefonte region in the Axemann Limestone and Bellefonte Dolomite, but not in the Nittany Dolomite. Yochelson and Bridge (1957) report occurrences of *Ceratopea buttsi* in the West Spring Creek Formation in the Arbuckle mountains in rocks believed to be equivalents of the Bellefonte Dolomite. Beneath these, in rocks which may be equivalent to the Axemann are *C. ankylosa* and *C. tennesseensis.* In central Pennsylvania *Ceratopea buttsi* is found in rocks which are believed to be either lower Bellefonte or upper Axemann equivalents, and *Ceratopea ankylosa* and *C. tennesseensis* are found in the Axemann Limestone.

Butts (1940) described 3000 feet of Beekmantown rocks above the Chepultepec Limestone in northeastern Virginia. He considered the Chepultepec to be equivalent to the Stonehenge Limestone, whereas the next higher 1200 feet were called lower Beekmantown. This latter sequence contains *Lecanospira compacta.* In overlying beds, classed as upper Beekmantown, fossils reported include *Maclurites affinis* and *Ceratopea tennesseensis,* both of which occur in the Axemann Limestone, as well as species of *Ophileta* and *Hormotoma.*

Woodward (1951) lists occurrences of *Diparalasma elegantulum, Hormotoma gracilens,* and *Turritoma acrea* in Beekmantown rocks of West Virginia.

It appears, therefore, that there is a fairly good correlation between the fauna of the Axemann Limestone, and the fauna found in Vermont, Maryland and Virginia in middle Beekmantown rocks above the occurrences of *Lecanospira compacta,* with the possible exception of associations described by Bassler in Maryland, where he reported both *Lecanospira ("Ophileta") compacta* and *Maclurites affinis* in the 600-foot *Cryptozoon steeli* zone, but without records of association in the same beds.

Even so, the occurrence of *M. affinis* offers approximate correlation of the Axemann Limestone with parts of middle Beekmantown rocks of other areas of the eastern United States, and this is considerably strengthened where the occurrences are above those of *Lecanospira compacta* and there is association with such fossils as *Tritoechia* sp., *Ceratopea ankylosa,* and *C. tennesseensis.*

HISTORY OF SEDIMENTATION AND PALEOGEOGRAPHY

INTRODUCTION

The environments of deposition of the Axemann Limestone are reflected in some degree in the rock composition, in the component type, size, and arrangement, and in the contained faunal assemblages. The characteristics of the components provide a basis for interpretation and speculation as to mode of origin as well as depth of water and strength of currents or waves. The available criteria are more applicable to the limestones than to the dolomites because original structures are extensively preserved in the limestones, whereas they tend to be destroyed in the dolomites. In consequence, views about origin of the dolomites are more questionable than those of the limestones. The stratigraphic and geographic distribution of rocks of different environments contributes to understanding of the broader aspects of the history of sedimentation and paleogeography.

ENVIRONMENTS AND HISTORY OF SEDIMENTATION

The Axemann Formation is formed by distinctive parts which differ markedly in rock features, and evidently represent important differences in conditions of sedimentation. Thus the Half-Moon Hill Member, which comprises the upper part of the Axemann in the Bellefonte - State College region, consists dominantly of calcilutite interbedded with dolomite. On the other hand, the Rockview Member which constitutes the lower part of the Axemann near Bellefonte and State College, and is represented by the entire Axemann Formation south of State College, is made principally of calcarenite interbedded with dolomite. The Rockview Member and south of State College the entire Axemann Formation which is limited to equivalents of the Rockview Member, is further subdivided into three parts. The upper and lower beds are composed mostly of lithic calcarenite interbedded with oolitic and fine-grained calcarenite, calcilutite, some pelmatozoan calcarenite and dolomite. The middle beds form a distinct unit consisting of pelmatozoan calcarenite interbedded

with dolomite and lesser amounts of calcirudite. The rocks of the Axemann Limestone mostly occur in units several feet thick, and more rarely 10 to 20 feet, which are composed dominantly of rocks of one lithotype. They commonly are banded and interbedded with subordinate percentages of rocks of the other lithotypes. Individual beds generally are several inches to a foot or so in thickness. In so far as rocks of the different lithotypes reflect different depositional environments, then the environments in which these rocks were deposited must have been fluctuating constantly.

The calcirudites together with the medium- and coarse-grained calcarenites represent deposition in comparatively high energy water where only the coarser grains of sedimentation were retained. The coarseness of the grains, the roundness of the grains, and the disarticulation of the fossils indicate agitation and winnowing by active currents or waves. The occurrence of oolites and the subordination of lime-mud are further indications of deposition in agitated waters. The concentric laminae of the oolites presumably were formed by either physicochemical or biochemical accretion during periods when the grains were rolled about and swept back and forth on the surface of sedimentation. The lack of lime-mud is most likely due to winnowing. The small amounts of lime-mud that occur in a few samples may represent residuals remaining after the bulk of the mud was winnowed, or may represent mud which worked its way down between grains at times when current activity diminished.

Compared to other rocks of the Axemann Limestone, the calcirudites accumulated in the areas of most active agitation, which were probably shoals or bars, over which waves may well have broken. Winnowing of the calcitic rubble may have supplied much of the finer sediment carried into somewhat less agitated water where coarse calcarenites were deposited. The fine-grained calcarenites presumably were deposited still farther from the areas of most active agitation where currents were able to remove only the lime-mud, and the lime-mud in turn, was deposited in quiet waters below wave base.

The grain-type as well as grain-size of the deposits also must have depended on the environments of the area of accumulation. If the sediments covering the shoal area were composed of semi-consolidated lime-mud or fine-grained lime-sand, the periodic breaking up of this material would form calcirudite with a matrix of lithic calcarenite, and the removal and later deposition of the lime-sand would have led to the formation of beds of lithic calcarenite. Cementation of the grains with sparry calcite must have occurred after the particles were at rest, but judging from the looseness of arrangement, grains in most studied examples evidently underwent cementation before there was significant

compaction. On the other hand, if the environment was one which permitted pelmatozoans to flourish, the derived deposits would have been composed of bioskeletal material of the pelmatozoan calcarenites. Perhaps the energy of this environment was too great for deposition of lime-mud. In the case of grains made of pelmatozoan plates, much of the sparry cement occurs as overgrowths, whereas in the lithic calcarenites it does not.

The oolitic calcarenites also may have formed on shallow banks in high energy environments in which the energy was too great for pelmatozoans to survive. The warming of colder waters coming over these banks may have precipitated calcium carbonate which built laminae around grains as they were being swept back and forth by active currents.

The fine-grained calcarenites mostly are composed of small, rounded, spherical to ovate pellets of microcrystalline calcite on the order of fine sand or coarse silt. Several hypotheses are offered to explain their origin. They may be grains of accretion which built up by being rolled about on the surface of sedimentation, though this is not apparent from their structureless nature. Perhaps they are grains of degradation resulting from the abrasion of larger calcilutite fragments, or they may be fecal pellets. Any or all of these hypotheses may be correct. Usually the pellets are found in a finely crystalline sparry cement and any lime-mud previously present may have been winnowed out. In the laminated, fine-grained calcarenites, thin layers of densely packed pellets are seen to alternate with thin layers of much less densely packed pellets in which the percentage of sparry cement is very high, and the pellets appear to float in the cement. The grains in the more densely packed layers may have been swept in and deposited in active currents which carried away any lime-mud which was present. If the current then diminished, lime-mud, instead of being swept away, would then be deposited together with a lesser amount of pellets, and, if the lime-mud later recrystallized, the pellets would appear to be floating in a sparry cement as is observed in thin section (Pl. 7, figs. 5-8). In some instances, finely divided bioskeletal material occurs in these rocks, and gastropod remains are not uncommon.

The calcilutites have apparently been deposited in quiet waters, but the mode of formation may have been quite variable. They may have been deposited in quiet water below wave base, or in shallower water protected by barriers from wave and current agitation. They may have been deposited through physicochemical precipitation from sea water or by biogenic processes. They may have been the result of deposition of microcrystalline calcite derived from the abrasion of bioskeletal ma-

terial or rock fragments. Perhaps all of these mechanisms played a part in the formation of the calcilutites. The scarcity of fossils in the calcilutites could be a result of unfavorable oxygen content, unfavorable salinity, or the extremely fine-grained nature of the sediment which would provide too sufficating an environment for most forms of life.

The origin of dolomitic mottling in the limestones is not clear, and additional research is needed to understand this phenomenon. Sando (personal communication) has suggested that perhaps sediment had been trapped by magnesium-rich algal mats, and subsequently altered by magnesium replacing calcium within the sediment. Other possibilities are that interlayered dolomite and lime-mud have been disturbed either by slumping or by burrowing animals, or perhaps magnesium-rich waters percolated along more permeable planes within the sediment altering parts of the sediment to dolomite.

The medium- to coarsely-crystalline dolomites, both mottled and unmottled, most likely represent limestones which have been altered to dolomites. Ghosts of originally granular structures represent the dolomitization of the more coarse-grained clastic limestones. Coarsely crystalline dolomites are rare within the Axemann, but they are more commonly seen in places where the Axemann grades laterally into dolomite beds. At some of these places, the coarseness of the crystallinity of the dolomite resembles that of coarsely crystalline pelmatozoan beds, and in thin sections of some samples of medium- to coarsely-crystalline dolomites, there are components which resemble pelmatozoan plates in size, shape, and in demonstrating unit extinction. In theory, these rocks once were pelmatozoan limestones which were altered to dolomite.

The majority of the dolomites within the Axemann Formation are finely crystalline, light gray, and commonly laminated. These dolomites suggest early replacement of microcrystalline calcite from the following characteristics. Idiomorphic dolomite has been observed in thin section to be penetrating and replacing parts of calcarenite components such as pellets, lithic calcarenite grains, and oolites where these components are composed of microcrystalline calcite. Individual dolomite rhombs are seen to be floating in a matrix of lime-mud in some calcilutites, and the difference in size between the coarser dolomite rhombs and the fine lime-mud suggests that these two components were not transported together. In this case, however, the dolomite may be growing in the mud and pushing it aside instead of replacing it. Finely crystalline, structureless dolomite occurs as laminae, bands and beds together with calcilutite. Perhaps the salinity of the environment of accumulation fluctuated so that at times preservation of lime-mud was favored, and at other times the alteration of lime-mud to dolomite was favored, thus giving rise to

dolomite layers parallel to bedding. Donaldson (1959) suggests that "slow deposition of lime-mud, and reaction with magnesium-enriched bottom waters could account for replacement of parts of limestone in the form of laminae, bands or beds. The microcrystalline calcite could either be replaced while being swept back and forth before final deposition, or while the muds still were soaked by sea water."

Quartz sand, where found, is more commonly associated with laminated dolomite, which suggests that these dolomites were in part clastic, and that the shallowing of the waters which favored dolomite deposition also brought the shoreline with its source of sand in closer proximity to the area of accumulation. The source of this sand may have been lowland areas to the north or northwest, or it may have been local uplifts (Swartz, 1948).

If the above depositional environments remained geographically stable, and if subsidence equalled sedimentary upbuilding, then the results should be stabilized facies, situated side by side, and separated by vertical boundaries. If, however, subsidence and sedimentary upbuilding fluctuated so that at one time subsidence was greater, placing the surface of sedimentation at any one place in deeper, quieter water, and at another time, upbuilding was greater, placing the surface of sedimentation at the same place in shallower, more turbulent water, then the environments would have migrated, and the results would be an interfingering of facies reflected in an interbedding of rocks of different lithotypes. This interbedding is what is observed in the field (Pls. 2 and 3.). Small scale interbedding involving layers only several inches thick or less, however, may be the result of intermittent periods of storms.

The rocks of the Rockview Member and its equivalents to the south suggest deposition in an environment of normal, shallow marine waters, which alternated with environments of quiet, restricted water when dolomite accumulated. The unit of pelmatozoan beds which consists of pelmatozoan calcarenites interbedded with finely crystalline dolomite indicates the fluctuation of shallow, high energy, normal marine environments which supported an abundance of life, with shallow, restricted, more saline conditions suitable for dolomite accumulation. The pelmatozoan beds may represent barrier bars which protected quiet, lagoonal areas where dolomite was being deposited, and the interbedding of the two rock types suggests that the environments were migrating back and forth due to the imbalance of subsidence and upbuilding.

The Half-Moon Hill Member consists dominantly of calcilutite interbedded with dolomite, and less dominantly of interbeds of coarser sediments, suggesting deposition in shallow, restricted, quiet water, interrupted occasionally by higher energy, normal marine conditions.

PALEOGEOGRAPHY

Schuchert (1955) has shown the distribution of the land and water on the North American continent during upper Canadian time. On his map, an extension of the sea trends in a northeasterly direction through the northeastern United States, with its western boundary bordering the broad interior lowland, and running from the southwestern corner of Pennsylvania diagonally across the state into central New York and eastern Canada. The eastern boundary runs from western New England southward through central New Jersey, flanking the eastern borderland, and then swings southwestward through Maryland and Virginia. Sediments of the Axemann Limestone were deposited during this time in this epeiric sea which bordered the low, interior landmass and was most likely shallow, warm, and super-saturated with calcium carbonate (Cloud and Barnes, 1948), and according to Swartz (1948) "It is probable that oceanic connections both northeast and southwest helped maintain the marine salinities of the time throughout most of the trough region."

The overall picture of Beekmantown stratigraphy (Swartz, 1948) shows that in the area of Pennsylvania covered by the sea, the rocks grade from shale in the east, through limestone in the central portion, to predominantly dolomite in the west. The dolomite could be a reflection of the shallowing of the water as it approaches the lowland to the west, and may well represent an environment of shallow, restricted water, of more than normal marine salinity, suitable for the formation of dolomite.

The distribution of the rocks of the Axemann Limestone together with their disappearance in certain places, essentially reaffirms the foregoing hypothesis. The Axemann Limestone was apparently deposited under normal marine conditions which permitted deposition of limestone. The Axemann disappears to the west where it has undergone a facies change into dolomite on the western flank of the Nittany Arch in the vicinity of Tyrone and southwest of Roaring Spring. The irregularity of the boundary separating the limestones on the east from the dolomites on the west may have formed shallow promontories of dolomite accumulation which protruded to the east into the Axemann seas. These promontories may have been the cause of the local disappearance of the Axemann where it has undergone facies change into dolomite at certain places on the eastern flank of the Nittany Arch. On the other hand, these areas of dolomite accumulation may be the result of local, island-like highs which persisted through Axemann deposition. (See Pl. 19)

Overlying the Axemann Limestone of the State College - Waterside region are the beds of the Bellefonte Dolomite. These beds reflect a restricted, shallow water environment, and suggest that the open marine conditions of Axemann deposition no longer existed, and perhaps these

rocks represent an eastward extension of the western area which was accumulating dolomite during the time of Axemann deposition. The beds of the lower Bellefonte Dolomite of this region are believed to grade laterally to the northeast into the interbedded calcilutite and dolomite of the Half-Moon Hill Member in the Bellefonte - State College region. The rocks of the Half-Moon Hill Member represent an area with a less saline environment which perhaps was a transitional zone between the more saline water to the west and the normal marine water to the east. The beds of this member grade to the southeast and northeast into rocks of the Coffee Run section and Lamar section which reflect normal marine conditions. The thickness of the Axemann Limestone at Coffee Run and Lamar is apparently due to either a longer period of normal marine deposition in these areas than in the Bellefonte-State College area, or a period during which sedimentation proceeded at a greater rate. Thin tongues of calcilutite in the lower 300 feet of Bellefonte Dolomite near Axemann may be extensions of the upper limestones at Coffee Run and Lamar, and represent slight transgressions of more normal marine conditions at that time. The Axemann Limestone of the Bellefonte - State College region, and the Lamar - Coffee Run region, is overlain by Bellefonte dolomite, indicating that the conditions which prevailed to the west, favoring the accumulation of dolomite during Axemann deposition, extended to the east at the close of the time the Axemann sediments were accumulating.

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APPENDIX A — PALEONTOLOGY

The faunal assemblage reported from the Axemann Limestone to date includes Brachiopoda, Gastropoda, Cephalopoda, Trilobita, and Ostracoda. Species collected during this study are illustrated and listed in the table below. Those not recognized previously are marked with an asterisk.

ILLUSTRATED FOSSILS

BRACHIOPODA

Diparalasma elegantulum (Butts)
Tritoechia cf. *T. pennsylvanica* Ulrich and Cooper
Tritoechia sp. indet.*

GASTROPODA

Ceratopea ankylosa Cullison*
Ceratopea buttsi Yochelson and Bridge*
Ceratopea tennesseensis Oder*
Hormotoma gracilens (Whitfield)
Maclurites affinis (Billings)
Ophileta cf. *O. solida* Butts
Turritoma cf. *T. acrea* (Billings)

CEPHALOPODA

gen. and sp. indet.*

TRILOBITA

Bathyurellus sp. 1
Bathyurellus sp. 2
Hystricurus sp. 1*
Hystricurus sp. 2*
Isoteloides sp.

Three trilobite species, *Bathyurellus* sp. 1 and sp. 2 and *Isoteloides* sp. were described originally by Macaulay (1952) in an unpublished Master's thesis. Macaulay named these species as follows: *Bathyurellus latimarginatus, Bathyurellus paracaudatus* and *Isoteloides triangularis.* Inasmuch as these descriptions are not published the new species names are not used herein.

In addition to the illustrated fossils several species have been reported from the Axemann Limestone. These were not found during the present study but are listed below.

REPORTED FOSSILS

BRACHIOPODA

Dalmanella subaequata gibbosa Billings

GASTROPODA

Coelocalus cf. *C. linearis* Butts
Hormotoma artemesia Billings
Liospira stratigata Collie
Prowarthia rossi Collie
Raphistoma columbiam Weller
Sinuopea cf. S. *umbilicus* Ulrich and Bridge

TRILOBITA

Bathyurus amplimarginatus Billings
Bolbocephalus sp. indet.

OSTRACODA

Ischilina sp.
Riberia sp.

APPENDIX B — SECTION DESCRIPTIONS AND LOCATIONS

Only the sections which are the type sections of the Axemann Limestone, and the Half-Moon Hill and Rockview Members are given here in their entirety. The location of all other sections shown in the plates are given also. Consult Lees (1964) for word description of the other sections.

BELLEFONTE SECTION
(No. 1)

The section at Bellefonte, Centre County, Pennsylvania, is the type section for the Axemann Limestone. The exposures begin in the Bellefonte Dolomite on a hillside, on the northwestern side of South Potter Street across from buildings of the Gypsum Board Company in southwestern Bellefonte, at about 10,000 feet west of 77° 45′ west longitude, and about 3500 feet south of 40° 55′ north latitude, and continue in a northeasterly direction along South Potter Street to the intersection with South Thomas Street, crossing beds in descending order. The section then is offset 1000 feet to the northeast, and continues at the intersection of South Water Street and High Street, and thence runs along South Water Street in a southerly direction. The beds strike N 55° E, dip 41° NW, and are concealed to the southwest.

Lower Ordovician Series

Unit	*Thickness (feet)* *Unit*	*Total*
Beekmantown Group		
Bellefonte Dolomite		
Dolomite, finely crystalline, medium-gray, weathers medium light gray, 1-foot bedded.	60	60
Axemann Limestone		
Half-Moon Hill Member		
Calcilutite, aphanitic, dark-gray, weathers light gray, laminated dolomitic, breaks with smooth, flat fracture across bedding, 1-foot bedded.	3	423
Calcilutite, algal, aphanitic to finely crystalline, somewhat calcarenitic, dark-gray, weathers medium light gray, in part mottled dolomitic, upper and lower contact irregular, 6-inch bedded.	3	420
Dolomite, aphanitic, dark-gray, weathers yellowish light gray, 6-inch to 1-foot bedded.	2	417
Concealed.	10	415
Dolomite, finely crystalline, brownish-gray, weathers light brownish gray, laminated, 1- to 2-inch bedded.	5	405
Calcilutite, aphanitic, dark-gray, weathers light gray, contains irregular silty seams, upper half irregularly mottled dolomitic, grading into 3-foot dolomite bed in middle, chert nodules near base, 1- to 2-foot bedded.	22	400
Dolomite, finely crystalline, medium-brownish-gray, weathers light olive gray, laminated, 1- to 2-foot bedded above, 0.5-inch bedded below.	7	378
Concealed.	21	371
Dolomite, brownish-gray, weathers light olive gray, mottled calcitic above, laminated, 0.25-inch banded in middle, otherwise 1- to 2-foot bedded. Vugular at base.	21	350
Calcilutite, aphanitic, dark-gray, weathers light gray, somewhat coarsely crystalline and oolitic in upper foot, middle part irregularly mottled dolomitic, grading down into sub-banded and banded dolomitic calcilutite. Mottling increases towards base, 3-foot bedded.	7	329
Dolomite, finely crystalline, medium-gray, weathers light olive gray, somewhat mottled, 2-foot bedded.	5	322
Calcilutite, aphanitic, dark-gray, weathers light gray, irregularly mottled dolomitic, densely mottled in upper foot, calcarenitic in lower foot, 6-inch to 1-foot bedded.	5	317
Dolomite, calcitic, finely crystalline, medium-brownish-gray, weathers light olive gray, faintly mottled, 1-foot bedded.	5	312
Calcilutite, somewhat calcarenitic, aphanitic, dark-gray, weathers light gray, irregularly mottled to sub-banded dolomitic, 2- to 3-foot bedded.	8	307

Unit		Thickness (feet) Unit	Total
	Calcilutite, aphanitic, dark-gray, weathers light gray, in places calcarenitic, mottled, banded, and interbedded with dolomite and some pelmatozoan and lithic calcarenite, stylolitic, contains irregular silty seams, some nodular chert, 6-inch to 1-foot bedded.	20	299
	Concealed. Section is continued 1000 feet to the northeast beginning again at the intersection of South Water Street and High Street and thence runs along South Water Street in a southerly direction.	100	279
	Rockview Member		
	Upper Calcarenite Beds		
	Dolomite, finely crystalline, medium-gray, weathers light olive gray, wavily laminated, vugular, 2- to 4-inch bedded.	4	179
	Calcarenite, lithic, medium-grained, finely crystalline, medium-dark-gray, weathers medium light gray, mottled dolomitic, 1-foot bedded.	3	175
	Calcarenite, pelmatozoan, coarse-grained, medium-crystalline, medium-dark-gray, weathers medium light gray, contains abundant fossil fragments, 2- to 3-inch bedded.	6	172
	Calcarenite, lithic, fine-grained, finely crystalline, medium-dark-gray, weathers medium light gray, mottled dolomitic, upper few inches calcilutite, 6-inch to 1-foot bedded.	3	166
	Dolomite, finely crystalline, medium-gray, weathers brownish gray.	1	163
	Calcarenite, oolitic, medium-grained, finely crystalline to medium-crystalline, medium-gray, weathers medium light gray, mottled dolomitic, 4- to 6-inch bedded. Contains fossils surrounded by concentric algal bands.	11	162
	Pelmatozoan Calcarenite Beds		
	Calcarenite, pelmatozoan, coarse-grained, coarsely crystalline, medium-dark-gray, weathers medium light gray, contains some dolomitic interbeds, 6-inch to 1-foot bedded.	12	151
	Dolomite, finely crystalline, medium-dark-gray, weathers light gray, somewhat mottled.	1	139
	Calcilutite, aphanitic, dark-gray, weathers light gray, somewhat calcarenitic, mottled dolomitic sub-parallel to bedding, 6-inch to 1-foot bedded.	3	138
	Dolomite, finely crystalline, medium-gray, weathers yellowish gray, vugular, somewhat mottled.	1	135
	Calcarenite, pelmatozoan, coarsely crystalline, coarse-grained, medium-gray, weathers medium light gray, somewhat dolomitic banded, 1-foot bedded.	4	134
	Dolomite, calcitic, finely crystalline, medium-dark-gray, weathers brownish gray, mottled light gray.	2	130
	Calcarenite, pelmatozoan, coarse-grained, coarsely crystalline, medium-gray, weathers medium light gray, 2-foot bedded.	2	128

Unit		Thickness (feet) Unit	Total
	Dolomite, finely crystalline, medium-gray, weathers light olive gray, laminated to banded, contains some bands of quartz sand, 2-foot bedded.	4	126
	Calcirudite, coarsely crystalline pelmatozoan matrix, medium-dark-gray, weathers medium light gray, somewhat banded dolomitic, contains abundant fossil fragments, 1-foot bedded.	4	122
	Dolomite, finely crystalline, medium-dark-gray, weathers medium light olive gray, mottled, banded with calcarenite, some calcilutite at top, 2-foot bedded.	5	118
	Calcarenite, pelmatozoan, coarse-grained, coarsely crystalline, medium-dark-gray, weathers medium light gray, 4- to 6-inch bedded, interbedded with dolomite.	4	113
	Dolomite, finely crystalline, light-olive-gray, weathers reddish brown, 2- to 3-inch bedded.	3	109
	Calcarenite, pelmatozoan, coarse-grained, coarsely crystalline, medium-gray, weathers medium light gray, contains some reddish pebbles, banded and interbedded with dolomite, 6-inch to 1-foot bedded. Fossils include *Maclurites affinis, Ophileta* sp., *Diparalasma* sp., *Tritoechia cf. T. pennsylvanica.*	7	106
	Dolomite, finely crystalline, medium-gray, weathers medium light gray, laminated to banded, contains quartz sand, 1- to 2-foot bedded.	7	99
	Calcirudite, pelmatozoan, coarsely crystalline, medium-gray, weathers medium light gray, irregularly banded dolomitic, 6-inch bedded.	2	92
	Dolomite, finely crystalline, medium-gray, weathers medium brownish gray, somewhat mottled.	2	90
	Calcarenite, pelmatozoan, coarsely crystalline, medium-dark-gray, weathers medium light gray, 4- to 6-inch bedded.	4	88
	Lower Calcarenite Beds		
	Dolomite, finely crystalline, medium-gray, weathers brownish gray, mottled, vugular, 1-foot bedded.	2	84
	Calcilutite, calcarenitic, aphanitic, medium-gray, weathers light gray, irregularly mottled to banded dolomitic, 2- to 4-inch bedded.	2	82
	Dolomite, finely crystalline, medium-gray, weathers medium light gray, banded to laminated, 1-foot bedded.	5	80
	Calcarenite, pelmatozoan above, lithic below, medium-crystalline, dark-gray, weathers light gray, contains abundant, irregular, silty seams, 2- to 4-inch bedded.	2	75
	Dolomite, finely crystalline, medium-brownish-gray, weathers light olive gray, somewhat mottled, banded near base.	1	73
	Calcarenite, pelmatozoan, medium-crystalline, medium-		

Unit		Thickness (feet) Unit	Total
	dark-gray, weathers light gray, stylolitic, contains abundant fossil fragments, 2- to 4-inch bedded.	1	72
	Dolomite, calcitic, finely crystalline, medium-light-gray, weathers light gray, very finely laminated, 2- to 4-inch bedded.	5	71
	Calcilutite, aphanitic, dark-gray, weathers light gray, in part calcarenitic, irregularly mottled dolomitic, intricately laced with thin, yellowish, irregular, discontinuous silty seams, 4- to 6-inch bedded.	4	66
	Dolomite, calcitic, medium-crystalline, brownish-gray, weathers medium brownish gray, mottled, contains some quartz sand.	4	62
	Calcarenite, pelmatozoan, medium- to coarsely-crystalline, medium-gray, weathers medium light gray, 2- to 6-inch bedded. Fossils include *Isoteloides* sp.	3	58
	Calcarenite, lithic, in part oolitic, fine- to medium-grained, dark-gray, weathers light gray, 1-foot bedded.	4	55
	Dolomite, finely crystalline, medium-brownish-gray, weathers light olive gray, somewhat mottled.	1	51
	Calcarenite, lithic, medium- to coarse-grained, oolitic above, fine-grained to calcilutite below, dark-gray, weathers light gray, irregularly mottled dolomitic, contains thin, discontinuous, irregular silty seams, 1-foot bedded above, 2-inch bedded below.	9	50
	Calcarenite, pelmatozoan, very coarse-grained, very coarsely crystalline, medium-dark-gray, weathers medium light gray, 4- to 6-inch bedded. Fossils include *Bathyurellus* sp., and unidentified gastropods.	5	41
	Calcilutite, aphanitic, dark-gray, weathers medium gray, jointed, beds separated by silty laminae, 2-inch bedded.	2	36
	Dolomite, finely crystalline, medium-dark-gray, weathers yellowish gray, mottled, upper few inches banded with calcilutite, 4- to 6-inch bedded.	3	34
	Calcarenite, pelmatozoan, coarse-grained, coarsely crystalline, medium-dark-gray, weathers medium light gray, 2- to 4-inch bedded. Fossils include brachiopods.	3	31
	Dolomite, finely crystalline, medium-dark-gray, weathers light yellowish gray, laminated, 1- to 4-inch bedded.	3	28
	Calcarenite, pelmatozoan, coarsely crystalline, medium-dark-gray, weathers medium light gray, 6-inch bedded.	3	25
	Dolomite, finely crystalline, light-gray, weathers yellowish gray, laminated.	1	22
	Calcarenite, lithic, medium-grained, aphanitic, medium-dark-gray, weathers light gray.	1	21
	Dolomite, medium-crystalline, coarsely crystalline at top, medium-gray, weathers yellowish gray to brownish gray, contains some chert nodules, 6-inch to 1-foot bedded.	4	20

Unit	Thickness (feet) Unit	Total
Calcarenite, lithic, medium- to coarse-grained, aphanitic, to finely crystalline, dark-gray, weathers medium light gray, mottled dolomitic, 4- to 6-inch bedded.	10	16
Dolomite, finely crystalline, medium-gray, weathers brownish gray, 3-inch bedded.	4	6
Calcarenite, lithic, medium-grained, finely crystalline, dark-gray, weathers medium gray, 3-inch bedded.	2	2
Concealed.	15	
Nittany Dolomite		
Dolomite, finely crystalline, medium- and coarsely crystalline, interbedded, 6-inch to 2-foot bedded.	100	100

HALF-MOON HILL SECTION
(No. 2)

The Half-Moon Hill section is located near Bellefonte, Centre County, Pennsylvania, about 10,000 feet east of longitude 77° 50′ W., 3500 feet south of latitude 40° 55′ N., and about one-half mile southeast of the village of Coleville. The exposures begin in the Bellefonte Dolomite in a road cut on the north side of a dirt road 630 feet west of its intersection with South Potter Street, and about 300 feet north of Spring Creek. The line of section runs in an easterly direction and crosses beds of the lower 183 feet of the Bellefonte Dolomite and the upper 124 feet of the Half-Moon Hill Member of the Axemann Limestone in descending order. The beds strike N 47° E, dip 42° NW, and are concealed to the east.

Lower Ordovician Series

Unit	Thickness (feet) Unit	Total
Beekmantown Group		
Bellefonte Dolomite		
Dolomite, fine- to medium-crystalline, brownish-gray, mottled, 1- to 3-foot bedded, discontinuous exposure.	183	
Axemann Limestone		
Half-Moon Hill Member		
Calcilutite, aphanitic, dark-gray, weathers medium light gray, mottled dolomitic, dolomite finely crystalline, 1- to 2-foot bedded.	12	124
Dolomite, finely crystalline, brownish-gray, mottled, 2-foot bedded.	6	112
Calcilutite, aphanitic, dark-gray, weathers medium light gray, mottled dolomitic, sub-parallel to bedding, weathered		

Unit		Thickness (feet) Unit	Total
	surface pitted where dolomitic mottling occurs. Contains thin irregular seams ¼ to ½ inch apart, 6-inch to 1-foot bedded.	4	106
	Dolomite, finely crystalline, brownish-gray, weathers light brownish gray, mottled, 2- to 3-inch bedded at top, 2-foot bedded at bottom.	6	102
	Calcilutite, aphanitic, dark-gray, weathers light medium gray, mottled dolomitic, 2- to 3-foot bedded. Contains thin irregular yellowish seams, and is sparsely banded with pelmatozoan calcarenite.	13	96
	Concealed.	7	83
	Calcilutite, aphanitic, dark-gray, weathers medium light gray, mottled dolomitic, slightly calcarenitic.	2	76
	Dolomite, calcitic, finely crystalline, brownish-gray, 2- to 4-inch bedded.	2	74
	Calcilutite, aphanitic, dark-gray, weathers medium light gray, mottled dolomitic, irregular at top, banded at bottom, calcarenitic near top with 1 foot of dolomite. Contains thin, irregular, yellowish seams, 1- to 3-foot bedded.	36	72
	Concealed.	6	36
	Calcilutite, aphanitic, dark-gray, weathers medium light gray with thin, irregular yellowish seams, interbedded with coarsely crystalline pelmatozoan calcarenite, coarse, lithic calcarenite near top, 2- to 4-inch bedded. Bottom 2 feet banded dolomitic.	9	30
	Concealed.	6	21
	Calcilutite, aphanitic, dark-gray, weathers medium light gray, 2- to 4-inch bedded, interbedded with fine-grained calcarenite.	3	15
	Concealed.	10	12
	Calcarenite, fine-grained, finely crystalline, dark-gray, weathers medium gray, contains large chert nodules.	2	2
	Concealed to the east.		

AXEMANN SECTION, N. E.
(No. 3)

The Axemann section, northeast, is located 1 mile south of Axemann, Centre County, Pennsylvania, about 3000 feet west of longitude 77° 45′ west, 15,000 feet south of latitude 40° 55′ north, on the northeastern side of the macadam road between Axemann, and Pleasant Gap, in a small quarry directly opposite the Farm Bureau. The exposures begin in the Bellefonte Dolomite, and the line of section runs in a northwesterly direction, crossing beds of the lower Bellefonte and Axemann in descending order. The beds strike N 55° E, dip 21° SE, and are concealed to the southeast.

AXEMANN SECTION, S. W.
(No. 4)

The section is located 1 mile south of Axemann, Centre County, Pennsylvania, about 3000 feet west of longitude 77° 45′ west, and 12,000 feet north of latitude 40° 50′ north, on the southwest side of the macadam road between Axemann and Pleasant Gap, in a hillside just southwest of the fish hatchery. The exposures begin in the Bellefonte Dolomite, and the line of section runs in a northwesterly direction, crossing the beds in descending order. The beds strike N 47° E, dip 17° SE, and are concealed to the southeast.

ROCKVIEW SECTION
(No. 5)

The section is located about 6 miles northeast of State College, Centre County, Pennsylvania, about 9500 feet west of longitude 77° 45′ west, and 10,000 feet north of latitude 40° 50′ north, in a quarry about 100 yards southeast of Route No. 26. The line of section begins in the Axemann Limestone, runs in a northwesterly direction, and crosses beds of the Axemann from top to bottom. The beds strike N 38° E, dip 24° SE, and the upper part of the formation, including the contact with the Bellefonte Dolomite, is concealed to the southeast.

Lower Ordovician Series

Unit	*Thickness (feet)* *Unit*	*Total*
Beekmantown Group		
Axemann Limestone		
Rockview Member		
Upper Calcarenite Beds		
Calcarenite, pelmatozoan, coarsely crystalline with interbeds of fine-grained calcarenite, calcirudite, and calcilutite, mottled dolomitic, and dolomite, 1- to 2-foot bedded. Dolomitic mottling, both irregular and sub-parrallel to bedding, standing in relief every few inches forming ridges and ledges. Contains thin yellowish, irregular seams. Fossils include *Maclurites affinis, Hormotoma* sp., *Turritoma* sp., abundant, weathering out on the surface, *Ceratopea tennesseensis, Bathyurellus* sp. 1.	12	151
Dolomite, slightly calcitic, finely crystalline, medium-gray, weathers yellowish gray, wavily laminated, 2-foot bedded. Quartz sand rare.	5	139

Unit		Thickness (feet) Unit	Total
	Calcarenite, lithic, medium- to coarse-grained, somewhat oolitic, finely crystalline to medium-crystalline, dark-gray, weathers medium light gray, somewhat mottled dolomitic, weathers with a pitted surface, 1-foot bedded.	3	134
	Calcarenite, pelmatozoan, coarse-grained, coarsely crystalline, medium-dark-gray, weathers medium light gray, with thin, silty laminae separating beds, banded with fine-grained calcarenite, calcilutite and calcirudite. Contains calcite-filled vugs 1 inch in diameter, 4-inch bedded. Fossils include *Maclurites affinis, Tritoechia* sp., *Isoteloides* sp., *Bathyurellus* sp. 2, Ostracodes.	5	131
	Calcarenite, coarse-grained oolitic, finely crystalline, dark-gray, weathers medium light gray, somewhat pelmatozoan, mottled dolomitic, grading down into calcitic vugular dolomite, 1- to 2-foot bedded. Fossils include *Maclurites affinis.*	4	126
	Calcarenite, oolitic, finely crystalline, dark-gray, weathers light medium gray, stylolitic, 2-foot bedded. Six inches of coarsely crystalline pelmatozoan calcarenite in the middle, algal concretions up to 1 inch surrounding crinoids (?) and *Hormotoma* sp. at base. Contains filled vugs. Fossils include *Maclurites affinis, Isoteloides* sp.	8	122
	Pelmatozoan Calcarenite Beds		
	Calcarenite, pelmatozoan, coarsely crystalline, dark-gray, weathers medium gray, silty laminae between beds, calcirudite at base, 2- to 3-inch bedded. Fossils include *Tritoechia* sp., *Isoteloides* sp.	8	114
	Dolomite, calcitic, finely crystalline, medium-gray, weathers yellowish gray, laminated, 3-foot bedded.	3	106
	Calcilutite, aphanitic, dark-gray, weathers medium light gray, mottled dolomitic, sub-parallel to bedding, banded calcarenitic, 1- to 2-inch bedded. Bedding planes separated by thin, silty laminae.	2	103
	Dolomite, finely crystalline, medium-gray, weathers light brownish gray, mottled.	2	101
	Calcarenite, pelmatozoan, very coarsely crystalline, medium-dark-gray, weathers medium light gray, 4- to 6-inch bedded. Bedding separated by thin dolomitic bands. Stylolitic. Upper surface very irregular, perhaps scoured, upper 6 inches is a very fossiliferous calcirudite. Fossils include *Maclurites affinis, Hormotoma* sp., *Tritoechia* sp., *Bathyurellus* sp. 1.	2	99
	Calcilutite, aphanitic, dark-gray, weathers light gray, irregularly banded dolomitic, contains bands and nodules of chert, 1- to 4-inch bedded. Some layers of gastropods. Fossils include gastropods.	3	97
	Calcarenite, pelmatozoan, very coarsely crystalline, dark-gray weathers medium light gray, mottled reddish, 4- to 6-		

Unit		Thickness (feet) Unit	Total
	inch bedded. Fossils include gastropods, and *Hystricurus* sp.	2	94
	Dolorudite, finely crystalline, medium-gray, weathers light yellowish gray, wavily laminated, contains quartz sand.	4	92
	Calcarenite, pelmatozoan, coarsely crystalline, medium-dark-gray, weathers medium gray, 2- to 4-inch bedded, banded dolomitic above. Contains some calcirudite, *Tritoechia* sp., *Ophelita* sp., *Hormotoma* sp., *Turritoma* sp.	3	88
	Calcilutite, aphanitic, dark-gray, weathers medium light gray, banded to mottled dolomitic, with thin irregular yellowish seams, 0.5- to 1-inch bedded, lower 6 inches pelmatozoan calcarenite.	2	85
	Dolomite, medium-gray, weathers yellowish medium light gray, banded to laminated, calcite-filled vugs 1 inch in diameter, 1-foot bedded, 6-inch shale layer at bottom.	3	83
	Calcirudite pelmatozoan, coarsely crystalline, medium-dark-gray, weathers medium light gray, with silty laminae between beds, somewhat mottled dolomitic sub-parallel to bedding, 4-inch to 1-foot bedded. Contains 6-inch sandy layer 3 feet from top. Fossils include abundant *Tritoechia cf. T. pennsylvanica.*	10	80
	Dolomite, finely crystalline, medium-gray weathers yellowish gray, mottled, streaked reddish.	2	70
	Calcarenite, pelmatozoan, coarsely crystalline, dark-gray, weathers medium gray, 6-inch to 1-foot bedded. Fossils include *Bathyurellus* sp. 1, gastropods.	2	68
	Dolomite, finely crystalline, brownish-gray, weathers yellowish gray, mottled, 1-foot bedded.	6	66
	Dolomite, finely crystalline, medium-gray, weathers yellowish brown, sandy at bottom, 2-foot bedded.	2	60
	Dolomite, finely crystalline, medium-gray, weathers yellowish gray, mottled, 1- to 2-foot bedded.	6	58
	Calcarenite, pelmatozoan, coarsely crystalline, dark-gray, weathers medium gray, mottled dolomitic, sub-parallel to bedding, with calcite-filled vugs, calcirudite and fossil fragments below, 4- to 6-inch bedded.	4	52
	Lower Calcarenite Beds		
	Dolomite, calcitic, finely crystalline, dark-gray, weathers medium light gray, wavily laminated, 1-inch band of chert at base.	1	48
	Calcarenite, fine-grained, finely crystalline, medium-dark-gray, weathers medium light gray, 6-inch to 1-foot bedded. Banded with coarsely crystalline calcarenite in middle, shaly towards bottom with dolomitic banding.	8	47
	Dolomite, finely crystalline, medium-gray, weathers medium light gray, laminated, 2-foot bedded, banded with quartz sand.	4	39

Unit		Thickness (feet) Unit	Total
	Calcilutite, aphanitic to finely crystalline, dark-gray, weathers light gray, mottled dolomitic, with thin, irregular, yellowish seams, 2- to 4-inch bedded. Contains irregular lenses of calcarenite.	2	35
	Dolomite, finely crystalline, medium-gray, weathers medium light gray to yellowish gray, laminated, banded with quartz sand, 1- to 2-foot bedded.	4	33
	Calcarenite, fine-grained, finely crystalline, dark-gray, weathers medium light gray, 1-foot bedded. Contains some bands of calcirudite and coarse-grained calcarenite.	8	29
	Dolomite, calcitic, finely crystalline, medium-gray, weathers medium light yellowish gray, mottled, 1-foot bedded, with abundant fossil fragments.	3	21
	Calcarenite, lithic, coarse-grained, interbedded with fine-grained calcarenite, finely crystalline, dark-gray, weathers medium light gray, 6-inch to 1-foot bedded. Contains a coarsely crystalline pelmatozoan zone 1 foot thick at the top and in the middle with an oolitic zone about 1 foot thick below each.	18	18
	Concealed to northwest.		

BENNER PIKE SECTION
(No. 6)

The section is located at State College, Centre County, Pennsylvania, about 3000 feet west of longitude 77° 50′ west, about 10,000 feet south of latitude 40° 50′ north, in a road cut on the northwestern side of the Benner Pike on the northeastern edge of State College, about 1400 feet northeast of the University Drive overpass. The line of section begins in the Axemann Limestone, runs in a southwesterly direction, and crosses beds of the Axemann from top to bottom. The beds strike N 22° E, dip 19° SE, and the upper Axemann and lower Bellefonte are concealed to the northeast.

RUPP QUARRY SECTION
(No. 7)

The section is located at State College, Centre County, Pennsylvania, about 7500 feet west of longitude 77° 50′ west, 14,000 feet north of latitude 40° 45′ north, in the Rupp Quarry on the northeastern side of South Atherton Street, about 300 feet east of the intersection of East Hamilton Street and South Atherton Street, State College, Pennsylvania. The line of section begins in the Axemann Limestone, runs in a westerly direction, and crosses beds of the Axemann from top to bottom. The beds strike N 28° E, dip 21° SE, and are concealed to the east.

SLAB CABIN CREEK SECTION
(No. 8)

The section is located just east of State College, Centre County, Pennsylvania, about 250 feet west of longitude 77° 50′ west, and 13,000 feet north of latitude 40° 45′ north, in a hillside just south of Route No. 322 where it crosses Slab Cabin Creek. The line of section begins in the Axemann Limestone, runs in a southerly direction, and measures the Axemann from top to bottom. The beds strike N 74° E, dip 40° SE, and are concealed to the north.

BAILEYVILLE SECTION
(No. 9)

The section is located at Baileyville, Centre County, Pennsylvania, about 4000 feet east of longitude 78° 00′ west, 15,000 feet north of latitude 40° 40′ north, in a field just west of Route No. 45, and just north of the Baileyville Road. The line of section begins in the Bellefonte Dolomite, runs in a southwest direction and crosses the beds in descending order. The beds strike N 53° E, dip 49° SE, and are concealed to the northeast. The interval is mostly concealed.

GRAYSVILLE SECTION NO. 1
(No. 10)

The section is located about half a mile southwest of Graysville, Huntingdon County, Pennsylvania, about 8000 feet west of longitude 78° 00′ west, 7000 feet north of latitude 40° 40′ north, along a hillside on the northeastern side of Spruce Creek. The traverse begins in the lower part of the Bellefonte Dolomite, and continues into the upper part of the Nittany Dolomite, crossing a sequence of dolomite in descending order in which the Axemann is not present as a limestone. The line of section runs in a northwest direction. The beds strike N 60° E, dip 55° SE, and are concealed to the southeast.

GRAYSVILLE SECTION NO. 2
(No. 11)

The section is located about half a mile southwest of Graysville, Huntingdon County, Pennsylvania, about 8500 feet west of longitude 78° 00′ west, 7800 feet north of latitude 40° 40′ north, along a hillside on the southwestern side of Spruce Creek, 400 feet southwest of the Graysville section No. 1. The line of section begins in the Bellefonte Dolomite, runs in a northwesterly direction and crosses beds in descending order. The beds strike N 50° E, dip 53° SE, and are concealed to the southeast.

GRAYSVILLE SECTION NO. 3
(No. 12)

The section is located 1 mile southwest of Graysville, Huntingdon County, Pennsylvania, about 11,000 feet west of longitude 78° 00′ west, 5000 feet north of latitude 48° 40′ west, on the northwestern bank of Spruce Creek. The line of section begins in the Bellefonte Dolomite, runs in a northerly direction, and crosses beds of the lower Bellefonte and the Axemann in descending order. The beds strike N 27° E, dip 53° SE, and are concealed to the south.

EVERGREEN FARM SECTION
(No. 13)

The section is located 1.5 miles southwest of Graysville, Huntingdon County, Pennsylvania, about 9500 feet east of longitude 78° 50′ west, 4000 feet north of latitude 40° 40′ north, in a hillside on the southeastern side of Route No. 45. The line of section begins in the Axemann Limestone, runs in a northwesterly direction and crosses beds of the Axemann in descending order. The beds strike N 57° E, dip 58° SE, and are concealed to the southeast.

SPRUCE CREEK SECTION
(No. 14)

The section is located about 1 mile northwest of Spruce Creek, Huntingdon County, Pennsylvania, about 7000 feet east of longitude 78° 10′ west, 14,000 feet north of latitude 40° 35′ north, in a road cut on the northeast side of the road between the village of Spruce Creek and Rural Choice School. The line of section begins in the Bellefonte Dolomite, runs in a northwesterly direction, and crosses beds in descending order. The beds strike N 69° E, dip 17° SE, and are concealed to the southeast.

LITTLE JUNIATA RIVER SECTION
(No. 15)

The section is located three-fourths of a mile northwest of Spruce Creek, Huntingdon County, Pennsylvania, about 5000 feet east of longitude 78° 10′ west, 11,500 feet north of latitude 40° 35′ north, on the northeastern bank of the Little Juniata River about three-quarters of a mile northwest of the village of Spruce Creek. The line of section begins in the Bellefonte Dolomite, runs in a northwesterly direction, and crosses beds in descending order. The beds strike N 55° E, and dip 27° SE.

GOODMAN SECTION
(No. 16)

The section is located three-fourths of a mile southwest of Goodman, Huntingdon County, Pennsylvania, about 1500 feet east of longitude 78° 10′ west, 15,000 feet north of latitude 40° 30′ north. The line of section begins in the Bellefonte Dolomite, and continues into what may be the upper part of the Nittany Dolomite, having gone through an interval where the Axemann Limestone is apparently missing, crossing beds in descending order. The beds strike N 30° E, dip 40° SE, and are concealed to the southeast.

MOUNT ETNA SECTION
(No. 17)

The section is one-fourth of a mile north of Mt. Etna, Blair County, Pennsylvania, about 1300 feet west of longitude 78° 10′ west, 7900 feet north of latitude 40° 30′ north, on the northeastern bank of the Franks-town Branch of the Juniata River, just east of the railroad track. The line of section begins in the Bellefonte Dolomite, runs in a northwesterly direction and crosses beds of the Bellefonte and the Axemann in descending order. The beds strike N 28° E, dip 37° SE, and are concealed to the southeast.

SPRING RUN SECTION
(No. 18)

The section is located 1 mile south of Mt. Etna, Blair County, Pennsylvania, about 2500 feet west of longitude 78° 10′ west, 2000 feet north of latitude 40° 30′ north. The line of section begins in the Bellefonte Dolomite on the south side of a stream valley, and runs in a westerly direction through a sequence of dolomite which is probably Axemann equivalent and is here considered to be lower Bellefonte and upper Nittany. The beds strike N 10° E, and dip 27° SE.

SHELLEYTOWN SECTION
(No. 19)

The section is located just north of Shelleytown, Blair County, Pennsylvania, about 11,800 feet west of longitude 78° 10′ west, 2600 feet south of latitude 40° 25′ north, on the east side of the macadam road 3.5 miles south of Williamsburg. The line of section begins in the Axemann Limestone, runs in a northwest direction, and crosses the beds in descending order. The beds strike N 26° E, dip 32° SE, and are concealed to the southeast.

BEAVERTOWN SECTION
(No. 20)

The section is located 1.25 miles southwest of Shelleytown, Blair County, Pennsylvania, about 14,500 feet west of longitude 78° 10′ west, 9200 feet south of latitude 40° 25′ north, in a small quarry about 100 yards east of the macadam road. The line of section begins in the Axemann Limestone, runs in a northwesterly direction, and crosses beds of the Axemann in descending order. The beds strike N 21° E, dip 43° SE, and are concealed to the southeast.

CURRYVILLE SECTION
(No. 21)

The section is located in a field 1.75 miles southwest of Curryville, Blair County, Pennsylvania, about 8000 feet west of longitude 78° 20′ west, 6000 feet north of latitude 40° 15′ north. The line of section begins in the Axemann Limestone, runs in a westerly direction, and crosses beds of the Axemann in descending order. The beds strike from N 27° W on the eastern end of the section to N 10° W on the western end, dip 14° NE, and are concealed to the east.

WOODBURY SECTION
(No. 22)

The section is located 1.5 miles south of Woodbury, Bedford County, Pennsylvania, about 11,000 feet east of longitude 78° 25′ west, 17,000 feet south of latitude 40° 15′ north, in a field just west of the macadam road between Woodbury and Waterside. The line of section begins in the Bellefonte Dolomite, runs in a northwesterly direction and crosses beds of the Axemann Limestone in descending order. The beds strike N 35° E, dip 26° SE, and are concealed to the southeast.

WATERSIDE SECTION
(No. 23)

The section is located half a mile northwest of Waterside, Bedford County, Pennsylvania, about 9000 feet east of longitude 78° 25′ west, 10,000 feet north of latitude 40° 10′ north, in a road cut on the northeast side of the macadam road between Maria and Waterside. The line of section begins in the Axemann Limestone, runs in a northwesterly direction and crosses the beds in descending order. The beds strike N 35° E, dip 32° SE, and are concealed to the southeast. The measured thickness of the section is greater than normal, and may be due either to faulting or to error in traversing a very thick concealed interval.

THE HALTER CREEK SECTIONS
(Nos. 24, 25, 26, and 27)

The Halter Creek sections are located about 2 miles southwest of Roaring Spring, Blair County, Pennsylvania. Four sections were measured along Halter Creek, the first of which is located on longitude 78° 25′ west, about 10,500 feet south of latitude 40° 20′ north, and 700 feet west of Route No. 867. The second section, Halter Creek section No. 2, is located 1400 feet southwest of the first section, the third section, Halter Creek section No. 3, is located 1630 feet southwest of the first, and the fourth section, Halter Creek section No. 4, is located 1910 feet southwest of the first section. The lines of section all begin in the Bellefonte Dolomite, run in a southeasterly direction, and cross the beds in descending order. The beds strike N 20° E, and are vertical. The amount of limestone decreases from north to south, and the Halter Creek section No. 4 is completely dolomite.

COFFEE RUN SECTION
(No. 28)

The section is located on the northeastern side of Coffee Run, Mifflin County, Pennsylvania, about 7000 feet east of longitude 77° 40′ west, 3500 feet south of latitude 40° 40′ north, in front of an Amish farm house, seven-tenths of a mile northwest of Route No. 76, along a macadam road. The line of section begins in the Bellefonte Dolomite, runs in a northwesterly direction and crosses beds of the lower Bellefonte and Axemann in descending order. The beds strike N 59° E, and dip 32° SE on the southeast part of the section, and they strike N 22° E and dip 10° SE on the northwest part of the section.

LAMAR SECTION
(No. 29)

The section is located at Lamar, Clinton County, Pennsylvania, about 9000 feet west of longitude 77° 30′ west, 7000 feet north of latitude 41° 00′ north, in a road cut at the intersection of Fishing Creek and Route No. 64 on the northern edge of the town of Lamar. The line of section begins in the Axemann Limestone, runs in a southwesterly direction and crosses the beds in descending order. The beds strike N 48° E, dip 27° SE, and are concealed to the northeast. The bottom half of the section is mostly concealed.

PLATES 1 - 12

PLATE 1. — SEDIMENTARY STRUCTURES

Figure 1. Calcilutite irregularly mottled dolomitic. Dark areas are dolomite, light areas calcilutite. Bellefonte section, 317 feet above base, in the Half-Moon Hill Member.

Figure 2. Calcilutite, mottled dolomitic, mottling is both irregular and sub-parallel to bedding. Dark areas are dolomite and light areas are calcilutite. Bellefonte section, 317 feet above base, in the Half-Moon Hill Member.

Figure 3. Calcilutite, mottled dolomitic above, irregularly mottled to sub-parallel to bedding, grading down into calcilutite sub-banded with dolomite. Dark areas are dolomite, light areas are calcilutite. Bellefonte section, 329 feet above base, in the Half-Moon Hill Member.

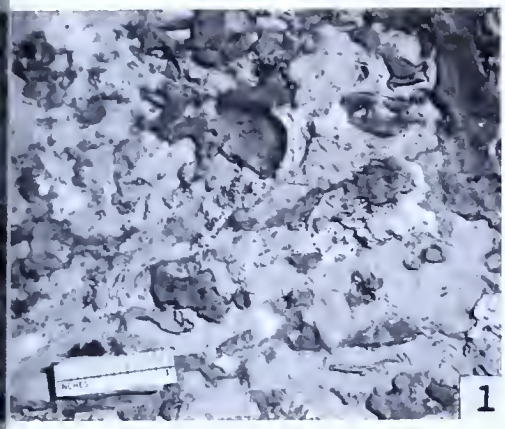
Figure 4. Calcilutite banded with dolomite. Bottom contact of dolomite band is sharp, upper contact gradational. Dark bands are dolomite, light bands calcilutite. Rockview section, 97 feet above base, in the Rockview Member.

Figure 5. Calcilutite banded with dolomite. Dark bands are dolomite, light bands calcilutite. Rupp Quarry section, 27 feet above base, in the Half-Moon Hill Member.

Figure 6. Calcarenite showing pitting on weathered surface. Rockview section, 134 feet above base, in the Rockview Member.

Figure 7. Calcilutite, showing irregular, anastomosing, silty seams, and some dolomitic laminae. Pelmatozoan calcarenite and calcirudite below scale. Bellefonte section, 290 feet above base, in the Half-Moon Hill Member.

Figure 8. Dolomite, laminated. Bellefonte section, 285 feet above base, in the Half-Moon Hill Member.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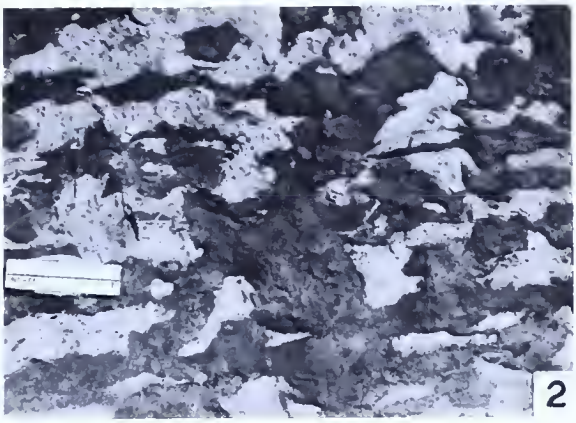
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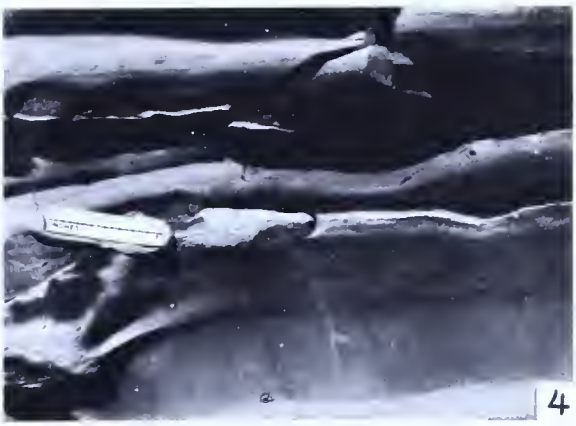
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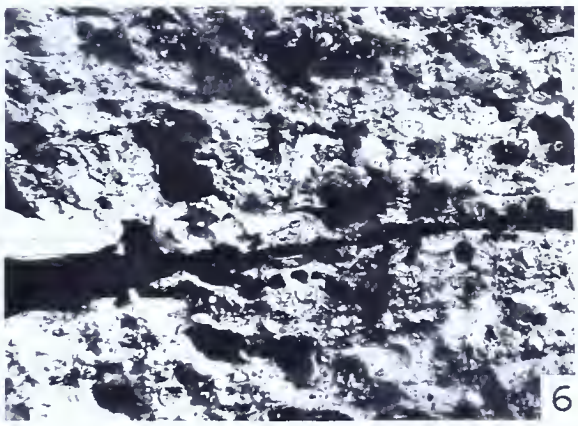
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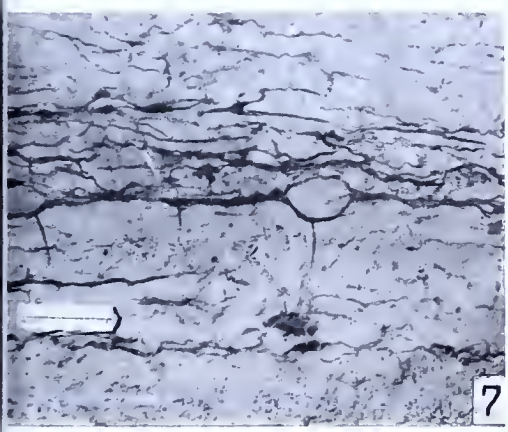
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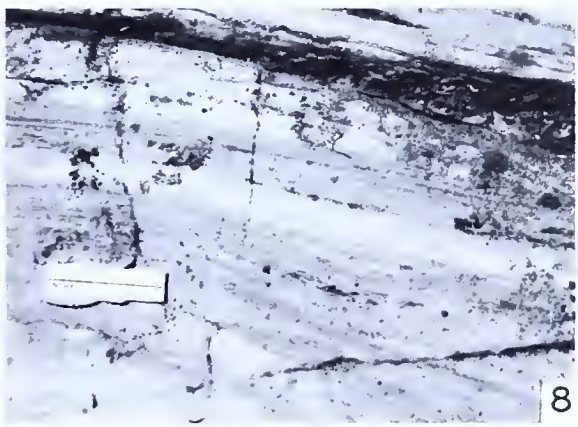
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PLATE 2. — SEDIMENTARY STRUCTURES

Figure 1. Algal limestone. Axemann section N. E., 379 feet above base, in the Half-Moon Hill Member.

Figure 2. Nodular and bedded chert in calcarenite. Rupp Quarry section, 41 feet above base, in the Half-Moon Hill Member.

Figure 3. Calcilutite bed with dolomite above hammer, and dolomite below ledge with hammer. Rupp Quarry section, 49 feet above base, in the Half-Moon Hill Member.

Figure 4. Hammer resting on calcirudite, dolomite above. Axemann section N. E., 129 feet above base, in the pelmatozoan calcarenite beds of the Rockview Member.

Figure 5. Calcilutite interbedded with pelmatozoan calcarenite. Axemann section N. E., 32 feet above base, in the lower calcarenite beds of the Rockview Member.

Figure 6. Interbedded calcilutite, calcarenite and calcirudite. Axemann section N. E., 210 feet above base, in the upper calcarenite beds of the Rockview Member.

1

2

3

4

5

Pelmatozoan Calcarenite

Calcilutite

Pelmatozoan Calcarenite

Calcilutite

Pelmatozoan Calcarenite

Calcarenitic Calcilutite

Calcilutite

Fine-Grained Calcarenite

6

Calcilutite

Pelmatozoan Calcarenite banded with Calcilutite

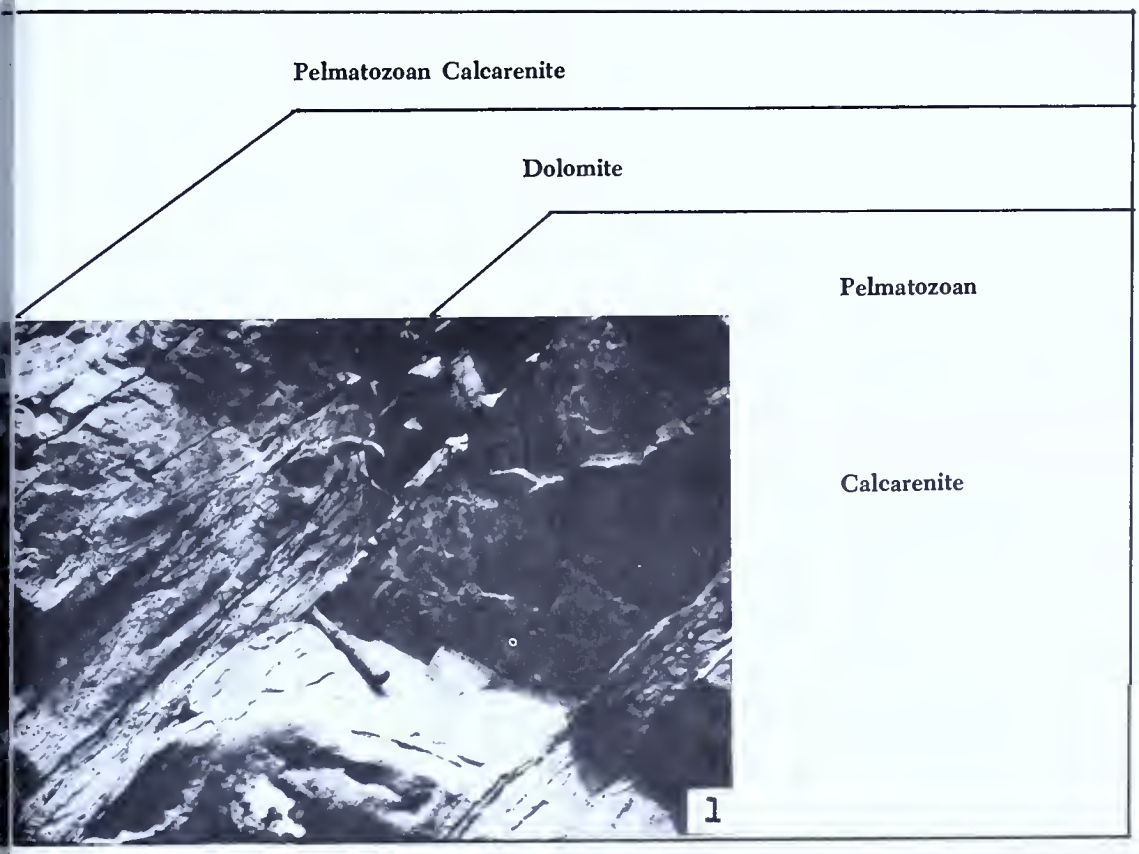
Calcirudite

Calcilutite

PLATE 3. — SEDIMENTARY STRUCTURES

Figure 1. Calcarenite, pelmatozoan, interbedded with finely crystalline, laminated to structureless dolomite. Bellefonte section, 113 feet above base, in the pelmatozoan calcarenite beds of the Rockview Member.

Figure 2. Calcarenite, pelmatozoan, interbedded with finely crystalline dolomite. Bellefonte section, 106 feet above base, in the pelmatozoan calcarenite beds of the Rockview Member.


Pelmatozoan Calcarenite
Dolomite
Pelmatozoan
Calcarenite
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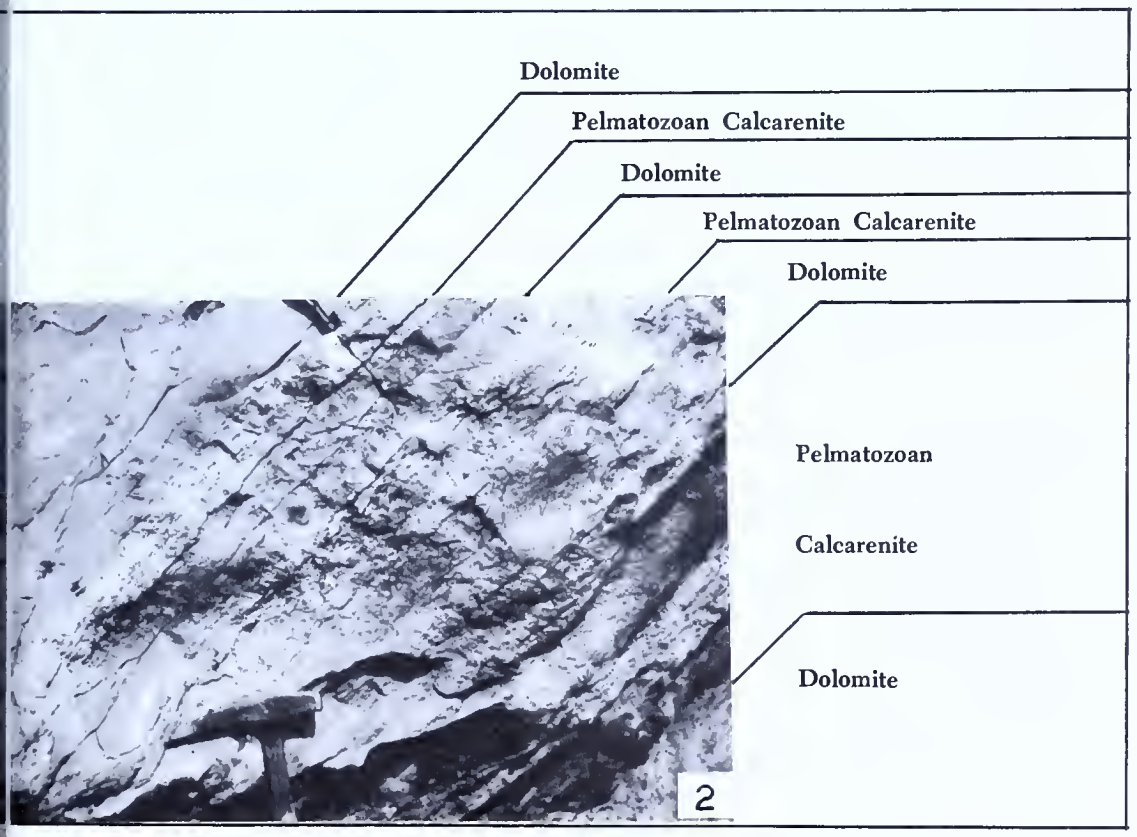

Dolomite
Pelmatozoan Calcarenite
Dolomite
Pelmatozoan Calcarenite
Dolomite
Pelmatozoan
Calcarenite
Dolomite
2

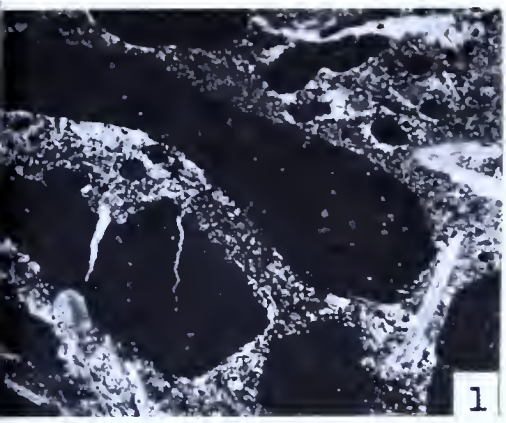
PLATE 4. — CALCIRUDITES (Figures are paired, X5 and X25)

Figures 1 and 2. Calcirudite, showing large, rounded to angular fragments of fine-grained calcarenite in a matrix of microcrystalline calcite pellets and lithic calcarenite cemented with finely crystalline sparry calcite. Figure 1 X5, Figure 2 X25. Axemann section N. E., 276 feet above base.

Figures 3 and 4. Calcirudite, showing rock fragments of rounded to sub-rounded, fine-grained calcarenite in a matrix of lithic calcarenite, cemented with sparry cement. Figure 3 X5, Figure 4 X25. Shelleytown section, 125 feet above base.

Figures 5 and 6. Calcirudite, showing fragments of fine-grained calcarenite in a matrix of lithic calcarenite and oolites. Figure 5 shows some gastropods. Figure 5 X5, Figure 6 X25. Axemann section S. W., 63 feet above base.

Figures 7 and 8. Calcirudite, showing fragments of fine-grained calcarenite and trilobite remains cemented in a mosaic of sparry carbonate. On the right side of Figure 7, and running across the middle of Figure 8, is a trilobite fragment partially replaced by small nodules of chert. Cavities beneath many of the larger grains are filled with sparry calcite. Figure 7 X5, Figure 8 X25. Axemann section N. E., 220 feet above base.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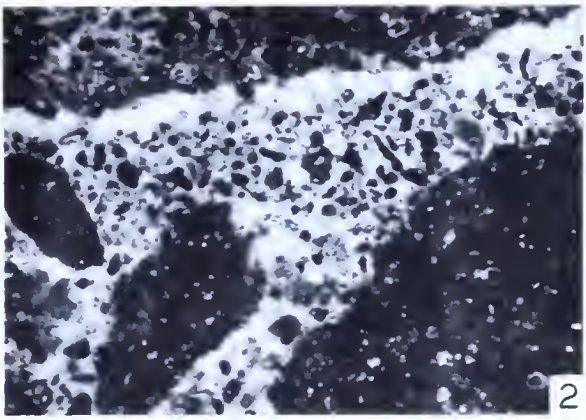
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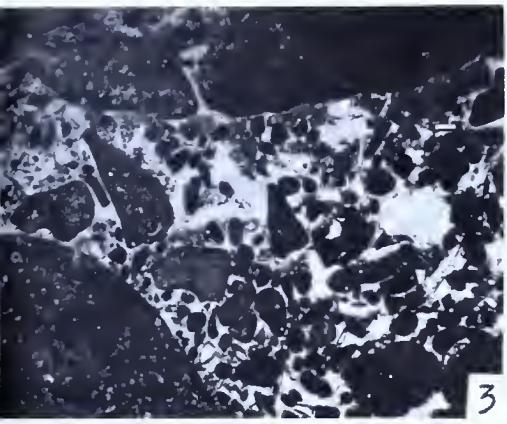
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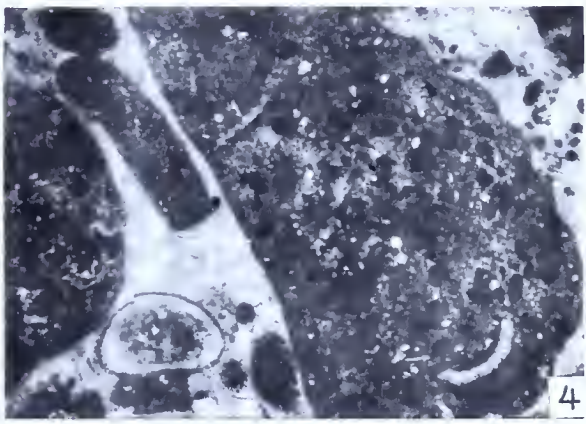
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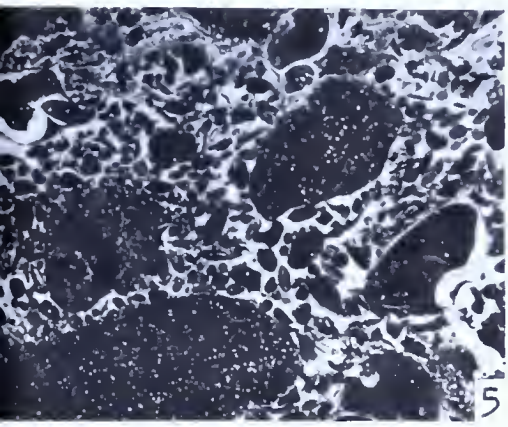
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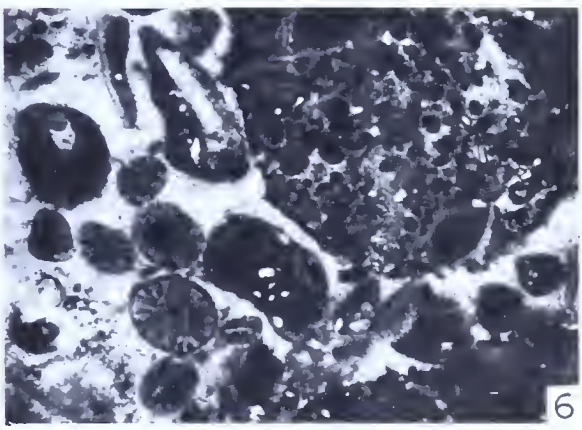
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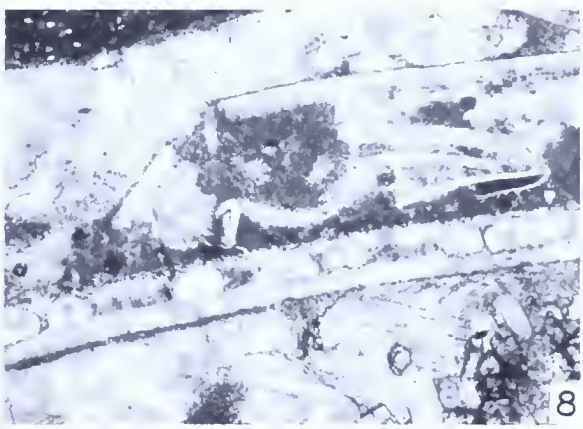
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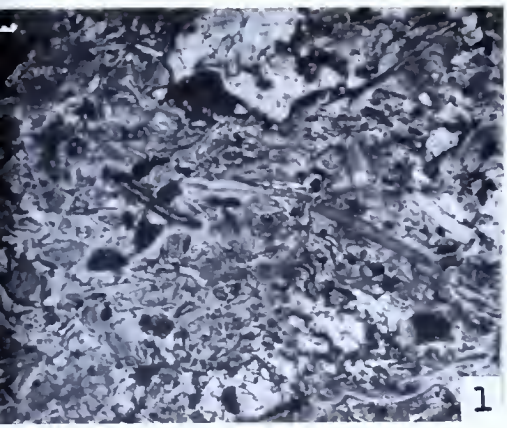
PLATE 5. — CALCARENITES (Figures are paired, X5 and X25)

Figures 1 and 2. Calcarenite, pelmatozoan, showing pelmatozoan plates and trilobite fragments in a sparry cement with rare lime-mud fragments. Figure 2 shows overgrowths on pelmatozoan plates. Lime-mud fragment a little above center is partially replaced by idiomorphic dolomite rhomb. Figure 1 X5, Figure 2 X25. Rockview section, 94 feet above base.

Figures 3 and 4. Calcarenite, pelmatozoan, showing pelmatozoan plates and trilobite fragments in a sparry cement. Rare grains of lithic calcarenite and lime-mud are present. Large pelmatozoan plate in center of Figure 4 shows overgrowth as well as the two smaller grains to the left. All show good cleavage. Figure 3 X5, Figure 4 X25. Rockview section, 114 feet above base.

Figures 5 and 6. Calcarenite, pelmatozoan, showing pelmatozoan plates, trilobite fragments, lime-mud filled gastropods and some lithic calcarenite in a sparry cement. Figure 5 shows what may be a pelmatozoan radial plate with an overgrowth of sparry cement. Rare lime-mud pellets are seen in Figure 6. Figure 5 X5, Figure 6 X25. Axemann section N. E., 147 feet above base.

Figures 7 and 8. Calcarenite, lithic, showing grains of lime-mud and fine-grained calcarenite up to 5 mm in diameter in a matrix of medium- to coarse-grained lithic calcarenite and bioskeletal material cemented with sparry calcite. Figure 7 X5, Figure 8 X25. Axemann section S. W., 26 feet above base.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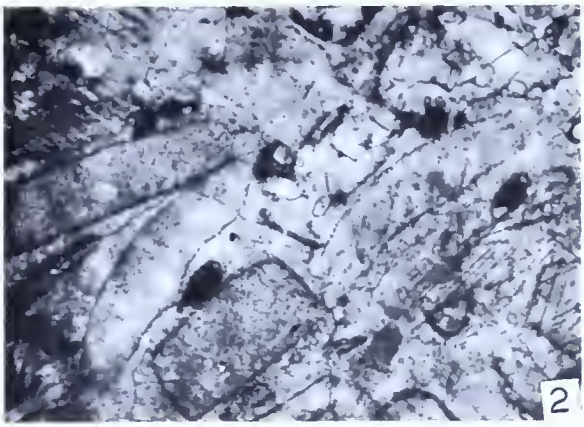
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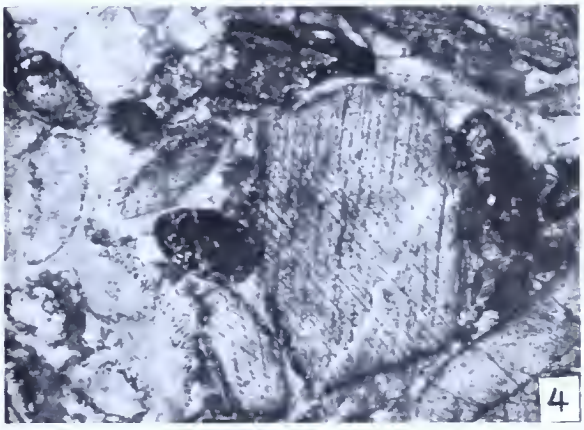
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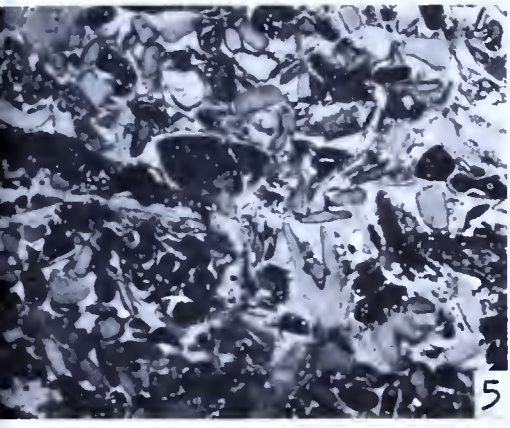
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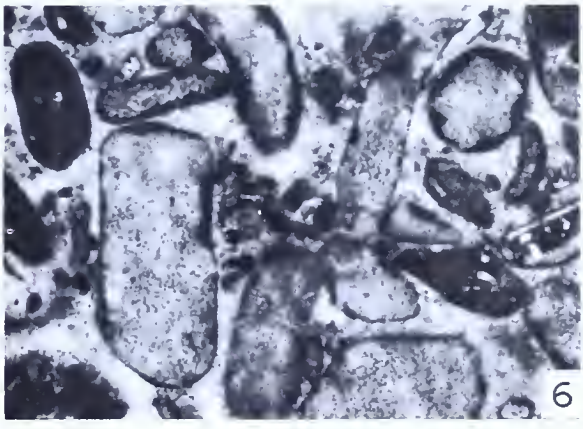
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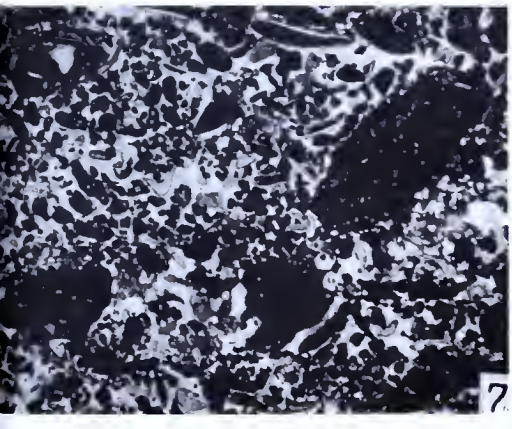
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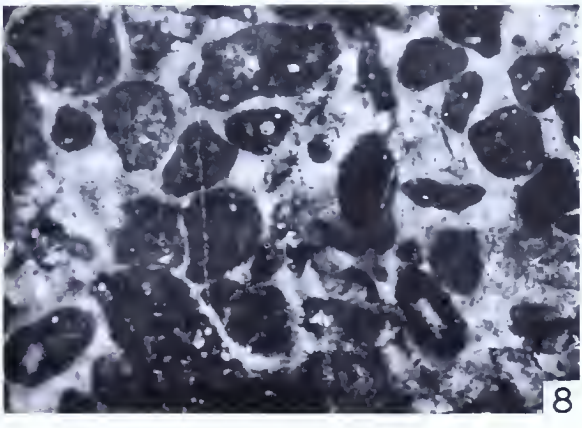
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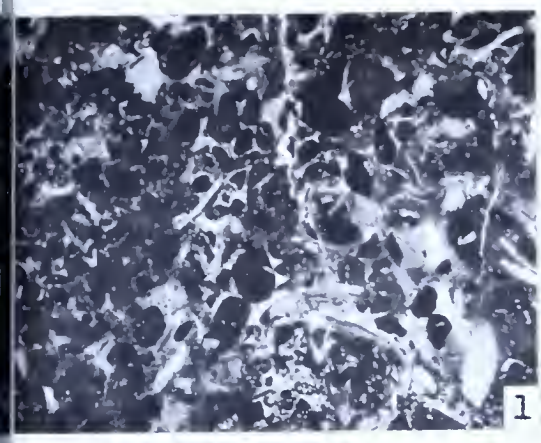
PLATE 6. — CALCARENITES (Figures are paired, X5 and X25)

Figures 1 and 2. Calcarenite, lithic, showing medium- to coarse-grained rounded to angular fragments of lime-mud together with lesser amounts of bioskeletal material in a calcilutite matrix and sparry calcite cement. Figure 1 X5, Figure 2 X25. Axemann section N. E., 48 feet above base.

Figures 3 and 4. Calcarenite, lithic, showing medium- to coarse-grained rounded to angular fragments of lime-mud and fine-grained calcarenite cemented with sparry calcite. Figure 3 X5, Figure 4 X25. Axemann section N. E., 48 feet above base.

Figures 5 and 6. Calcarenite, oolitic, showing medium-grained oolites in a sparry cement. Oolites appear to consist of laminae surrounding a nucleus of lime-mud. Figure 5 X5, Figure 6 X25. Rockview section, 16 feet above base.

Figures 7 and 8. Calcarenite, oolitic, showing medium-grained oolites together with mud-filled gastropods in a mosaic of sparry cement. Figure 8 shows both the radial and concentric structure of the oolites. Figure 7 shows doubly terminated quartz crystal with a quartz sand grain as a nucleus at right of picture, and several other quartz grains with overgrowths. Figure 7 X5, Figure 8 X25. Bellefonte section, 329 feet above base.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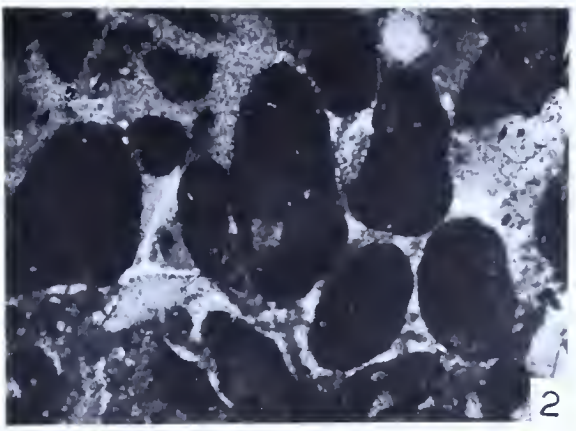
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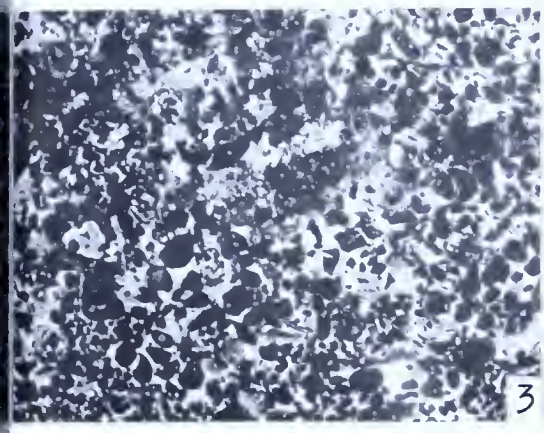
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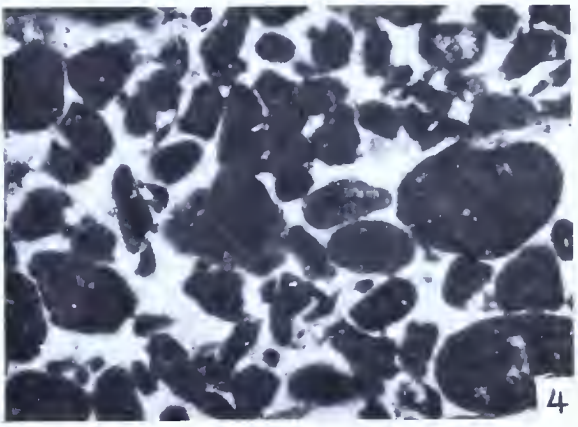
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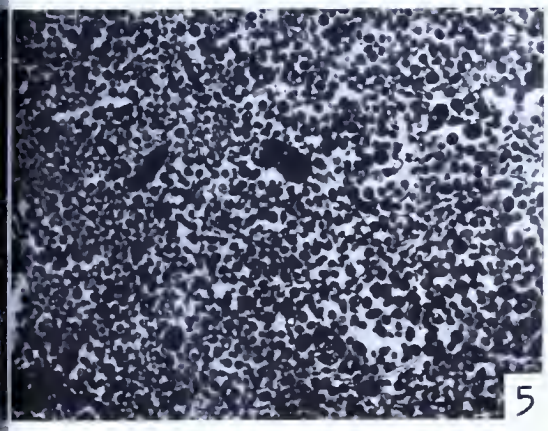
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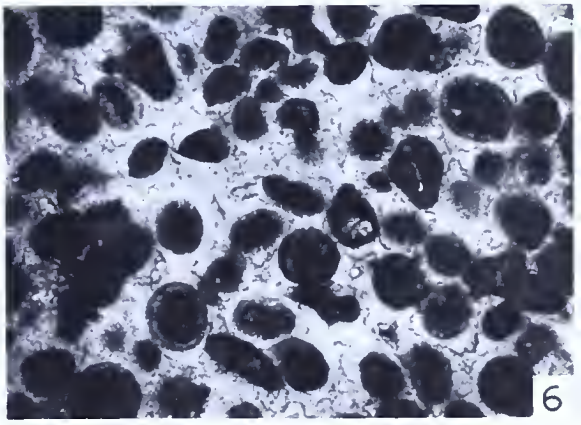
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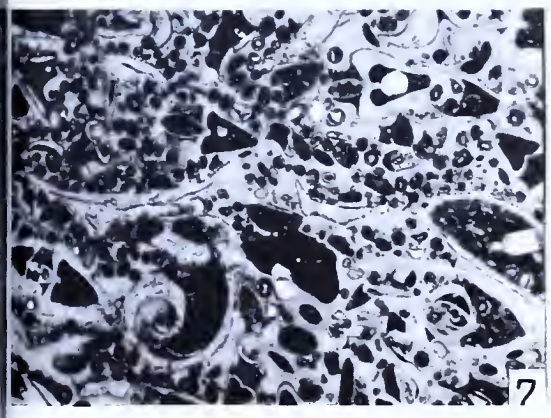
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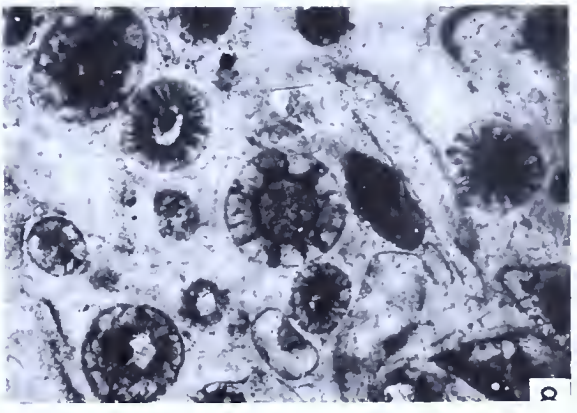
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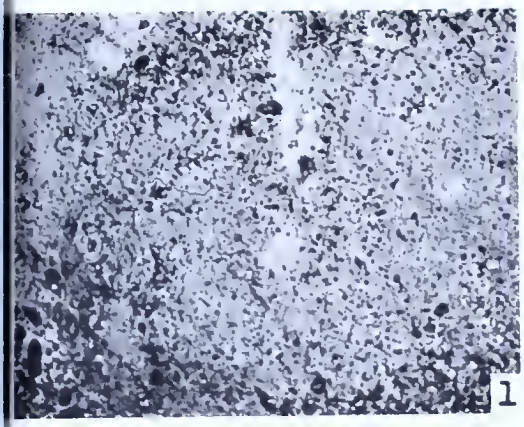
PLATE 7. — CALCARENITES (Figures are paired, X5 and X25)

Figures 1 and 2. Calcarenite, oolitic, dolomitic, showing fine- to medium-grained oolites and lime-mud fragments in a sparry calcite and dolomite cement. Figure 2 shows oolites and lime-mud fragments partially replaced by idiomorphic dolomite. Figure 1 X5, Figure 2 X25. Axemann section S. W., 43 feet above base.

Figures 3 and 4. Calcarenite, fine-grained, showing microcrystalline lime-mud pellets in a lime-mud matrix, cemented with microcrystalline sparry calcite. Bioskeletal fragments abundant. Figure 3 X5, Figure 4 X25. Rockview section, 140 feet above base.

Figures 5 and 6. Calcarenite, fine-grained, laminated, showing pellets of lime-mud in a microcrystalline sparry calcite cement. Lesser amounts of bioskeletal material are present. Darker laminae of densely packed pellets alternate with light laminae of less densely packed pellets with a higher percentage of sparry calcite. Figure 5 X5, Figure 6 X25. Axemann section S. W., 121 feet above base.

Figures 7 and 8. Calcarenite, fine-grained showing pellets of lime-mud in a mosaic of sparry calcite. Laminations of densely packed pellets alternate with laminations of less densely packed pellets. Figure 7 X5, Figure 8 X25. Benner Pike section, 194 feet above base.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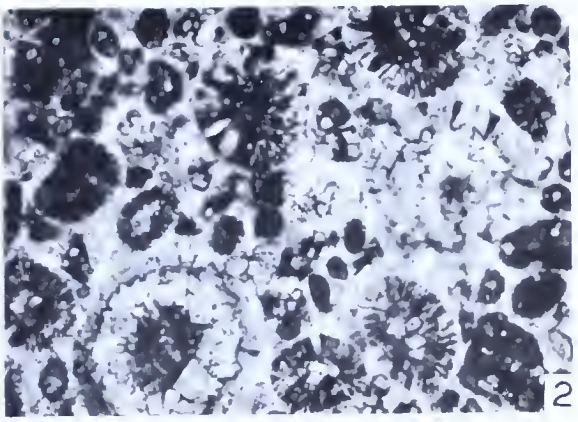
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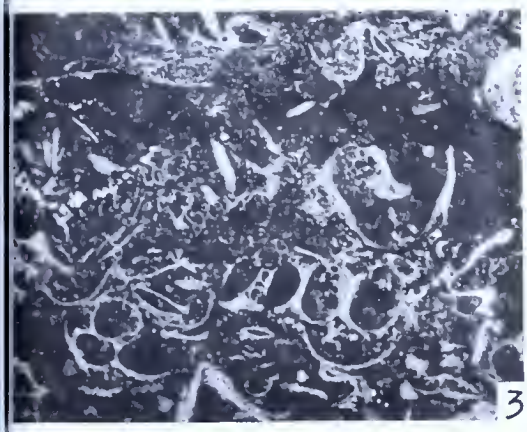
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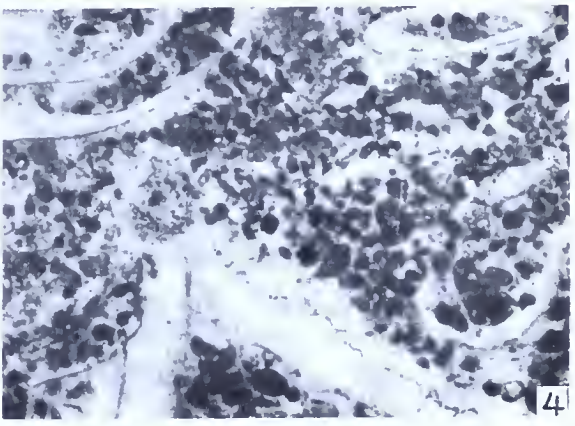
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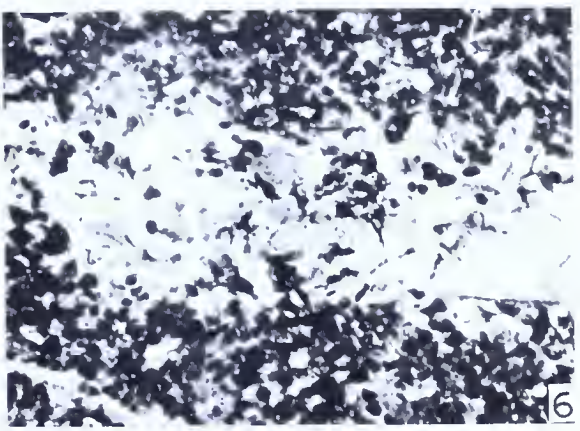
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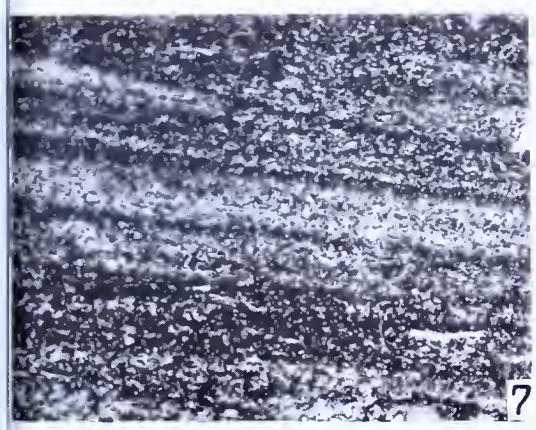
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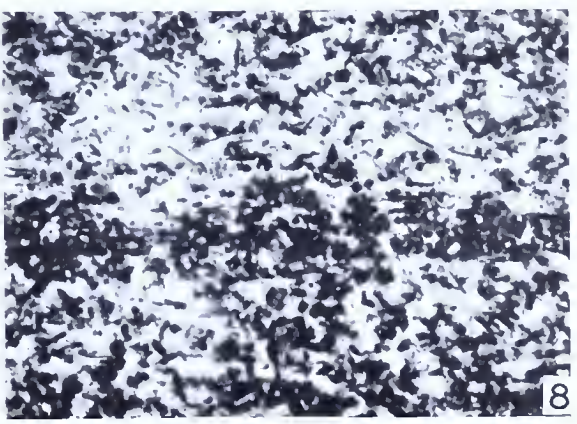
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PLATE 8. — CALCILUTITE AND DOLOMITE (Figures are paired, X5 and X25)

Figures 1 and 2. Calcilutite, showing stylolites and fractures. Fractures filled with sparry calcite. Figure 1 X5, Figure 2 X25. Rupp Quarry section, 64 feet above base.

Figures 3 and 4. Calcilutite. Figure 4 shows small dolomite rhombs in the lime-mud. Figure 3 X5, Figure 4 X25. Rupp Quarry section, 24 feet above base.

Figures 5 and 6. Calcilutite below, structureless, finely crystalline dolomite above, showing stylolitic contact, and dolomite rhombs in calcilutite. Figure 5 X5, Figure 6 X25. Rockview section, 97 feet above base.

Figures 7 and 8. Dolomite, cross-laminated, finely crystalline, showing idiomorphic to xenomorphic dolomite crystals. Figure 7 X5, Figure 8 X25. Bellefonte section, 312 feet above base.

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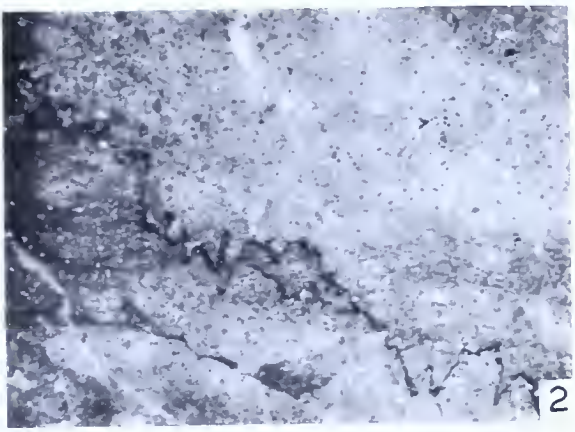
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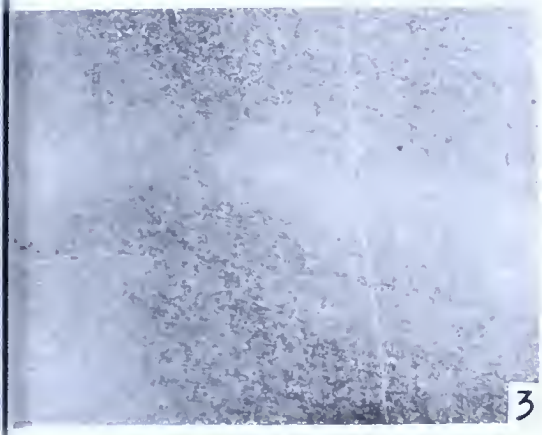
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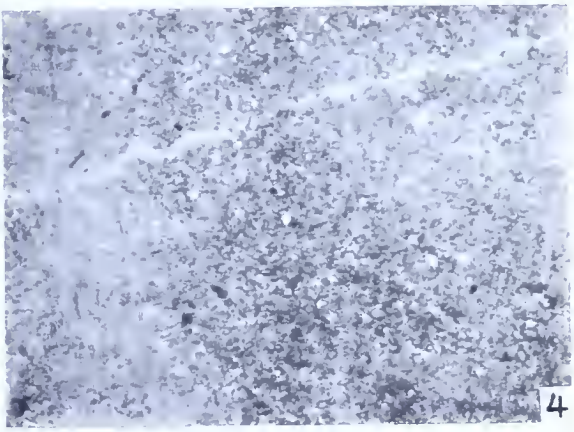
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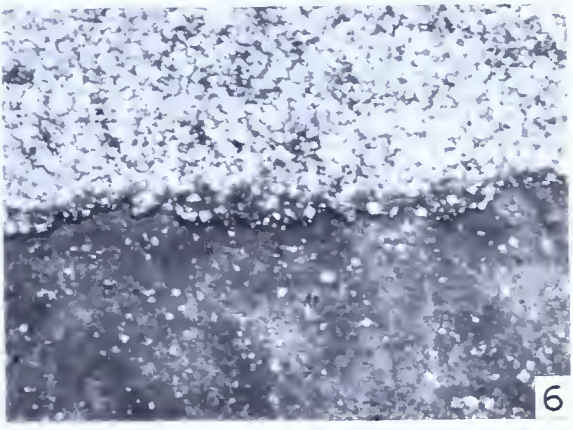
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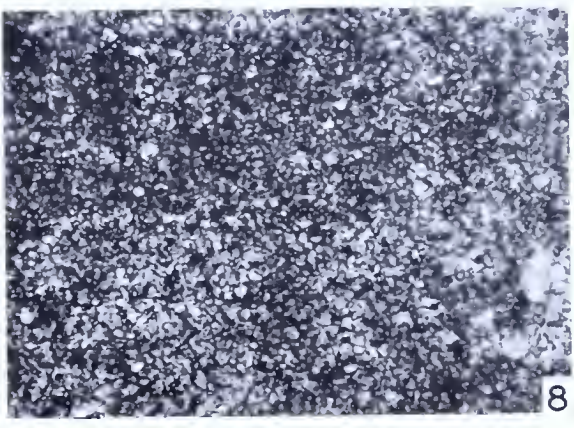
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PLATE 9. — DOLOMITE (Figures are paired, X5 and X25)

Figures 1 and 2. Dolomite, laminated, finely crystalline, showing laminae of finely crystalline, idiomorphic to xenomorphic dolomite alternating with aphanitic clayey dolomite. Figure 1 shows a few quartz grains. Figure 1 X5, Figure 2 X25. Bellefonte section, 350 feet above base.

Figures 3 and 4. Dolomite, mottled, medium crystalline, showing patches of xenomorphic, sparry dolomite and mottling which may be ghosts of a previously coarsely clastic structure, in a groundmass of medium-crystalline, idiomorphic dolomite. Figure 3 X5, Figure 4 X25. Rockview section, 58 feet above base.

Figures 5 and 6. Dolomite, mottled, medium- to coarsely crystalline, showing coarse, sparry dolomite and patches of silty or clayey material in a medium-crystalline, xenomorphic to idiomorphic groundmass. Figure 5 X5, Figure 6 X25. Little Juniata River section, 81 feet above base.

Figures 7 and 8. Dolomite, finely crystalline, sandy, showing rounded to angular etched quartz grains about 0.5 mm in diameter in a groundmass of finely crystalline xenomorphic to idiomorphic dolomite. Above the quartz sand is very finely crystalline structureless dolomite. Figure 7 X5, Figure 8 X25. Shelleytown section, 35 feet above base.

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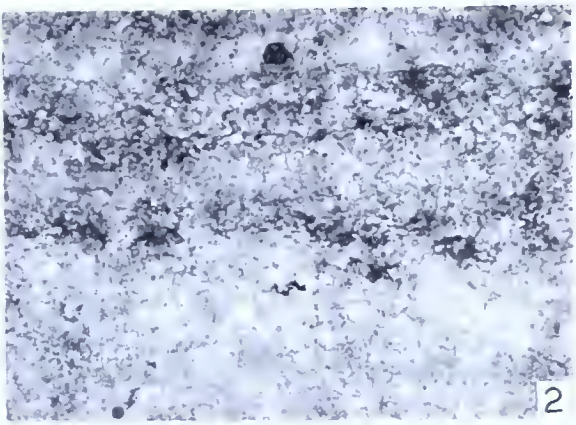
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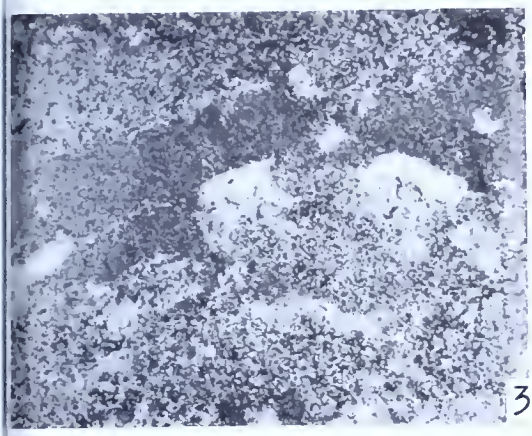
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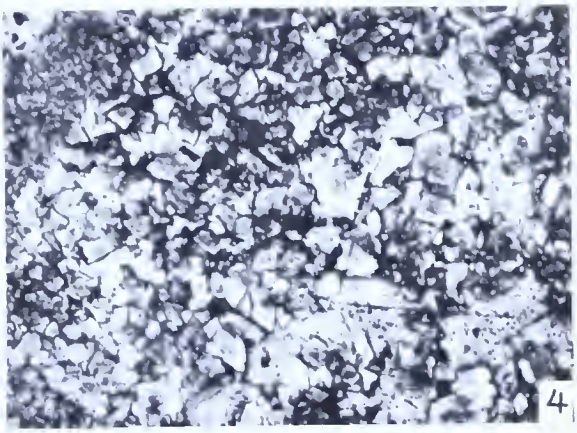
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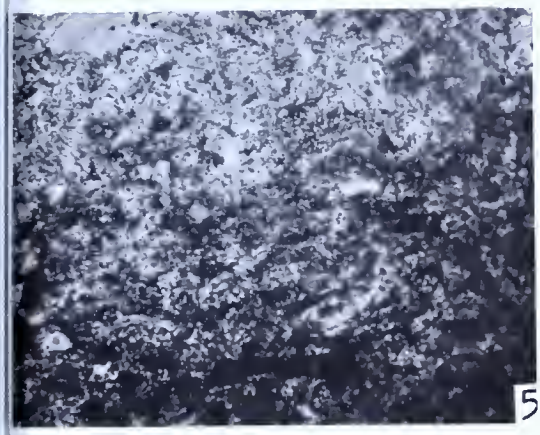
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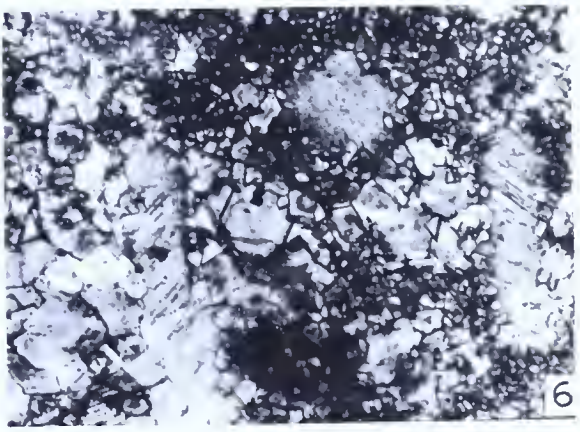
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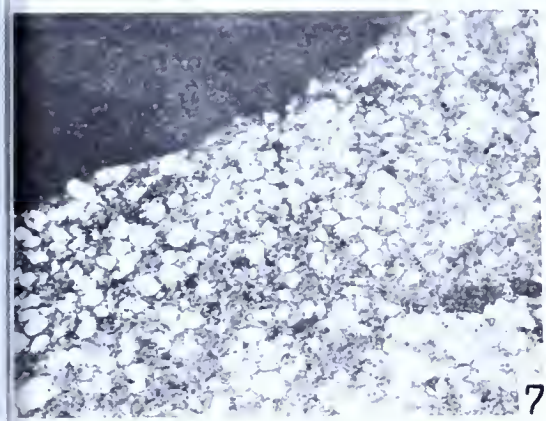
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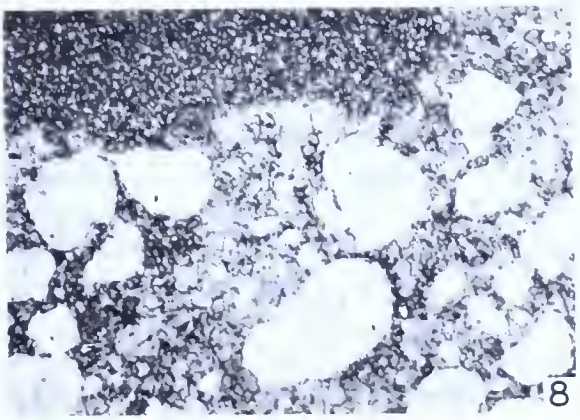
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PLATE 10. — FOSSILS FROM THE AXEMANN LIMESTONE

Figures 1-12, *Tritoechia cf. T. pennsylvanica*

Figure 1. Interior view of pedicle valve (X5) showing dental plates bounding delthyrial cavity, oblique view of interarea and open foramen. Axemann section N. E., 220 feet above base.

Figure 2. Exterior view of pedicle valve (X5). Axemann section N. E., 220 feet above base.

Figure 3. Interior view of pedicle valve (X5) showing interarea, hinge teeth and foramen. Graysville section no. 3, 15 feet above base.

Figure 4. Interior view of brachial valve (X5) showing straight hinge line and erect cardinal process. Axemann section N. E., 220 feet above base.

Figure 5. Exterior view of brachial valve (X5) showing growth lines and costellae. Axemann section N. E., 220 feet above base.

Figure 6. Interior view of brachial valve (X5) showing straight hinge line, sockets, erect cardinal process, brachiophores very nearly parallel to hinge line, and median ridge. Mt. Etna section, 77 feet above base.

Figure 7. Exterior view of brachial valve (X5) showing costellae and shallow, anterior sulcus. Graysville section no. 2, 15 feet below the Axemann-Nittany contact in dolomite equivalent to lower Axemann.

Figure 8. Exterior view of pedicle valve (X5) showing costellae and shallow anterior sulcus. Graysville section no. 2, 15 feet below the Axemann-Nittany contact in dolomite equivalent to the lower Axemann.

Figure 9. Interior view of pedicle valve (X5) showing dental plates. Mt. Etna section, 77 feet above base.

Figure 10. Interior view of brachial valve (X5), same as Figure 7, showing straight hinge, erect cardinal process, sockets, brachiophores sub-parallel to hinge line, and shallow anterior sulcus. Graysville section no. 2, 15 feet below the Axemann-Nittany contact in dolomite equivalent to the lower Axemann.

Figure 11. Interior view of pedicle valve (X5) showing dental plates. Graysville section no. 2, 15 feet below the Axemann-Nittany contact in dolomite equivalent to the lower Axemann.

Figure 12. Interarea of pedicle valve (X5) showing fine converging lines, convex pseudodeltidium, and open, apical foramen. Graysville section no. 2, 15 feet below the Axemann-Nittany contact in dolomite equivalent to the lower Axemann.

Figures 13-16, *Tritoechia sp. indet.*

Figure 13. Exterior view of brachial valve (X5) showing straight hinge line and costellae. Spring Run section, 200 feet above base.

Figure 14. Interior view of brachial valve (X5) showing hinge line, sockets, and strongly developed brachiophores diverging from hinge line at about 45 degrees. Spring Run section, 200 feet above base.

Figure 15. Interior view of pedicle valve (X5) showing oval outline of shell, foramen, interarea, teeth, and dental plates. Spring Run section, 200 feet above base.

Figure 16. Exterior view of pedicle valve (X5) showing oval outline of shell, and costallae. Spring Run section, 200 feet above base.

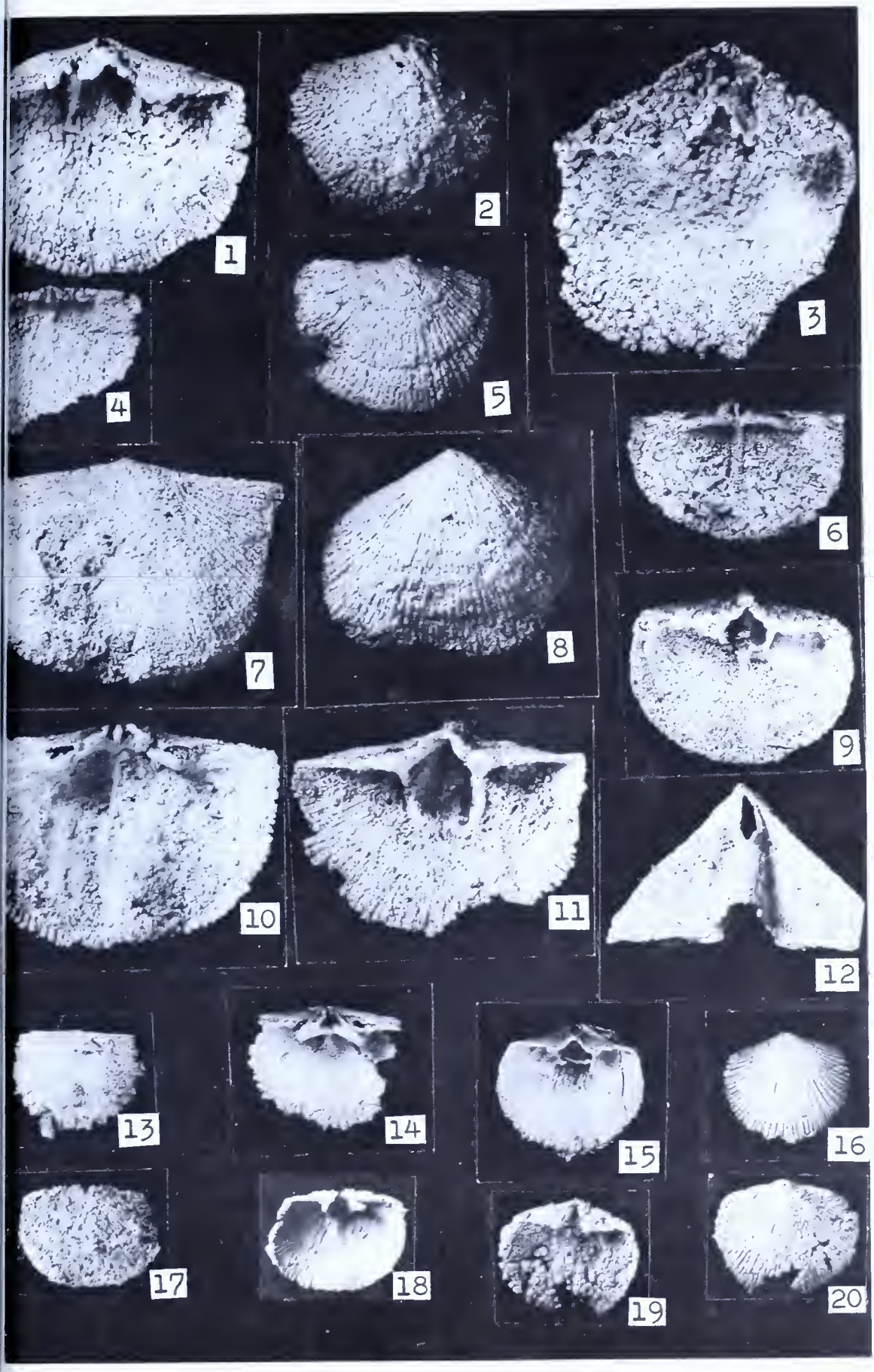
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PLATE 10. — CONTINUED

Figures 17-20, *Diparalasma cf. D. elegantulum*

Figure 17. Exterior view of brachial valve (X5) showing transversely elliptical outline of shell. Mt. Etna section, 77 feet above base.

Figure 18. Interior view of brachial valve (X5) showing well developed brachiophores. Mt. Etna section, 77 feet above base.

Figure 19. Interior view of pedicle valve (X5) showing interarea, delthyrium, and hinge teeth. Mt. Etna section, 77 feet above base.

Figure 20. Exterior view of pedicle valve (X5) showing swollen umbonal region and costellae. Mt. Etna section, 77 feet above base.

PLATE 11. — FOSSILS FROM THE AXEMANN LIMESTONE

Figure 1. Ventral view of *Maclurites affinis* (X3). Axemann section N. E., 220 feet above base.

Figure 2. Cross section of *Maclurites affinis* (X4) showing expanding whorl profile, upper part of each whorl is acute, lower part more gently rounded. Axemann section N. E., 147 feet above base.

Figure 3. Dorsal view of *Ophileta cf. O. solida* (X2.2). Bellefonte section, 106 feet above base.

Figure 4. Cross section of *Ophileta cf. O. solida* (X2.4), showing strongly arched whorl profile, showing individual whorl with an acute peripheral profile and a gently rounded lower whorl profile. Axemann section N. E., 212 feet above base.

Figures 5-7. *Hormotoma cf. H. gracilens,* showing rounded whorl profile. Figure 7 shows *H. gracilens* surrounded by concretions which may be algal. Figure 5 (X5), Rockview section, 150 feet above base. Figure 6 (X2.5), Axemann section S. W., 77 feet above base. Figure 7 (X2), Rockview section, 115 feet above base

Figure 8. *Turritoma cf. T. acrea* (X3.5), showing flattened whorl with bottom rounded and protruding slightly over one below. Axemann section N. E., 146 feet above base.

Figure 9. Dorsal view of *Ceratopea ankylosa* (X2), showing parietal surface and wide dorsal angle. Rupp Quarry section, 76 feet above base.

Figure 10. Ventral view of *Ceratopea tennesseensis* (X3), Halter Creek section No. 4, 70 feet above base.

Figure 11. Dorsal view of *Ceratopea buttsi* (X2), showing gently curved, thick operculum. Spring Run section, 440 feet above base.

Figure 12. Dorsal view of *Ceratopea tennesseensis* (X3), showing carinal surface, dorsal ridge, parietal surface, and rather wide dorsal angle. Rockview section, 150 feet above base.

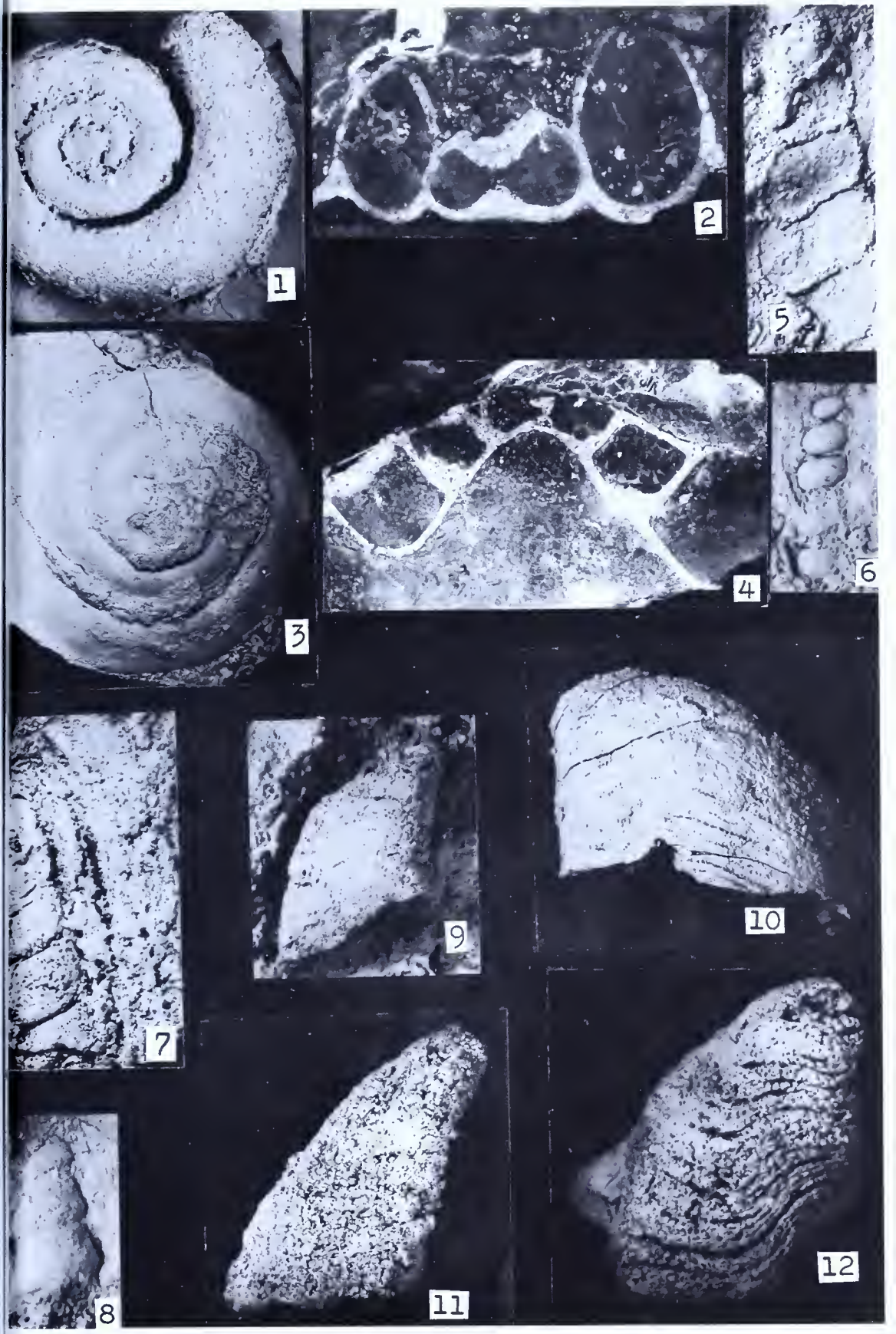
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PLATE 12. — FOSSILS FROM THE AXEMANN LIMESTONE

Figure 1. *Isoteloides* sp. pygidium (X3.3), showing weak trilobation, axial lobe regularly tapering, weakly defined, anterior margin gently curving, posterior margin more strongly curving. Axemann section S. W., 148 feet above base.

Figure 2. Pygidium, *Isoteloides* sp. (X3.7), similar to Figure 1. Rockview section, 114 feet above base.

Figure 3. Glabella, *Isoteloides* sp. (X4), showing anterior brim and occipital ring. Shelleytown section, 88 feet above base.

Figure 4. *Bathyurellus* sp. 2 pygidium (X4), showing strong lobation, depression at distal end of posterior half of second pleural segment, and thick axial spine. Axemann section N. E., 147 feet above base.

Figure 5. *Bathyurellus* sp. 2 pygidium (X4.4), similar to Figure 4. Spruce Creek section, 159 feet above base.

Figure 6. *Bathyurellus* sp. 1 glabella (X2.50), convex, showing curved anterior margin, straight posterior margin, straight, strong, dorsal furrows. Rockview section, 68 feet above base.

Figure 7. *Bathyurellus* sp. 1 pygidium (X4.4), showing strong trilobation similar to *B. paracaudatus*, but lacking terminal spine. Little Juniata River section, 34 feet above base.

Figure 8. *Bathyurellus* sp. 1 pygidium (X6), similar to Figure 7. Shelleytown section, 83 feet above base.

Figure 9. Hypostome, *Isoteloides* sp. (X2), showing posterior prongs, notch, brim, raised dome with two posterior pits. Benner Pike section, 65 feet above base.

Figure 10. *Bathyurellus* sp. 1 pygidium (X5), similar to Figures 7 and 8. Shelleytown section, 88 feet above base.

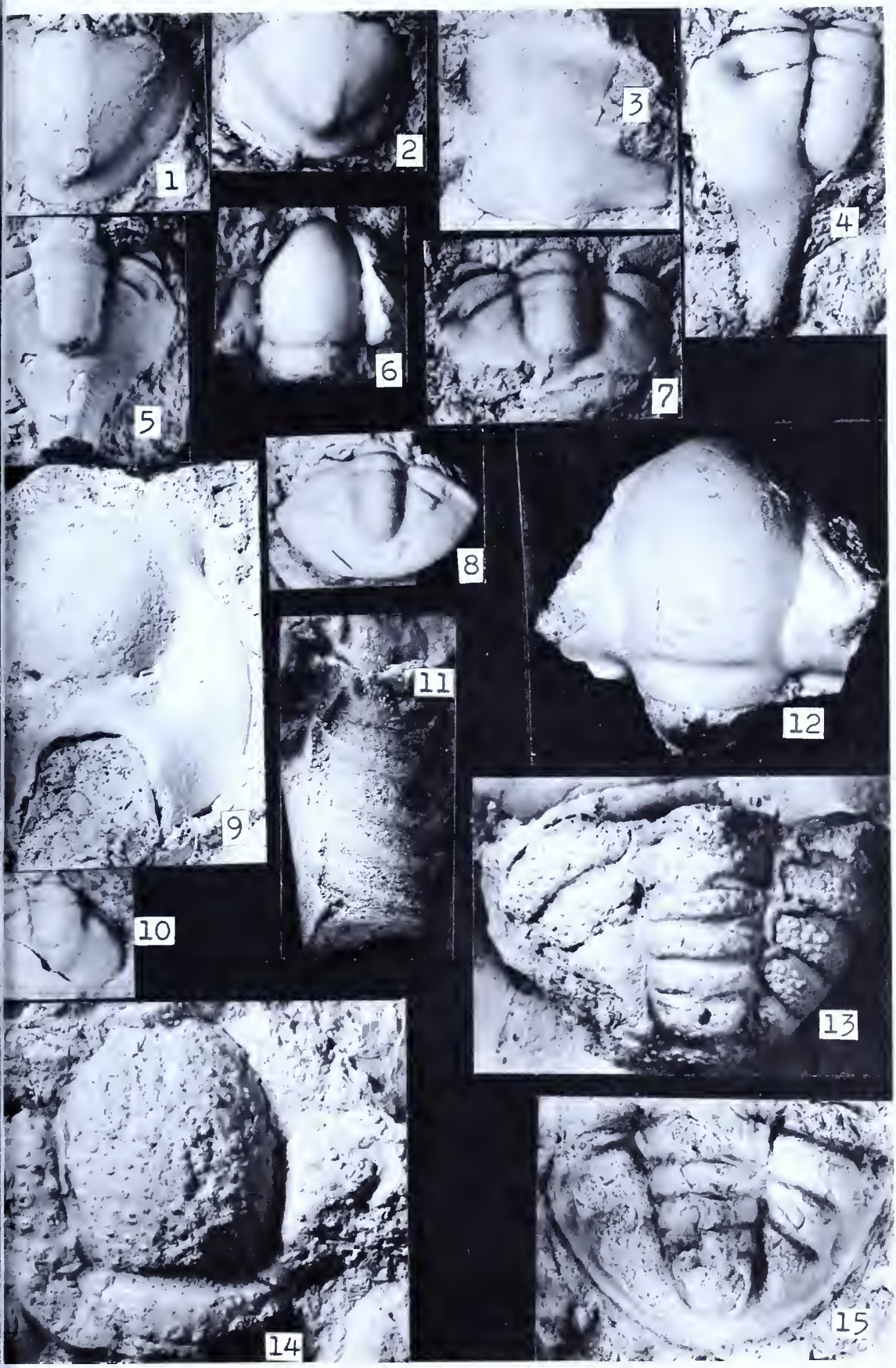
Figure 11. Cephalopod siphuncle, (X2), straight siphuncle with oblique septal markings. Rupp Quarry section, 76 feet above base.

Figure 12. *Hystricurus* sp. 2 glabella (X5), moderately pustular, expanding forward. Little Juniata River section, 34 feet above base.

Figure 13. *Hystricurus* sp. 1 pygidium (X4), strongly trilobate, coarsely pustular. Axemann section N. E., 147 feet above base.

Figure 14. *Hystricurus* sp. 1 glabella (X4), anterior margin curved, posterior margin straight, coarsely pustular, expanding forward. Axemann section N. E., 168 feet above base.

Figure 15. *Hystricurus* sp. 2 pygidium (X3), strongly trilobate, moderately pustular. Axemann section N. E., 212 feet above base.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THE AXEMANN LIMESTONE
BELLEFONTE-STATE COLLEGE REGION

JOHN ALLEN LEES

1 BELLEFONTE
2 HALF-MOON HILL
3 AXEMANN N.E.
4 AXEMANN S.W.
5 ROCKVIEW
6 BENNER PIKE
7 RUPP QUARRY
8 SLAB CABIN GREEK

BELLEFONTE DOLOMITE

HALF-MOON HILL MEMBER

AXEMANN LIMESTONE

ROCKVIEW MEMBER

NITTANY DOLOMITE

UPPER CALCARENITE BEDS

PELMATOZOAN CALCARENITE BEDS

LOWER CALCARENITE BEDS

SCALE IN FEET
50
25
0

BEDDING
LESS THAN 6-INCH BEDDED
6- INCH TO 2-FOOT BEDDED
2- TO 6-FOOT BEDDED

COMPOSITION AND TEXTURE
CALCILUTITE
PELMATOZOAN CALCARENITE
LITHIC CALCARENITE
OOLITIC CALCARENITE
PHEDRAMED CALCARENITE
CALCILUTITE
FINELY CRYSTALLINE DOLOMITE
MEDIUM- TO COARSELY CRYSTALLINE DOLOMITE
SOLE RUGITE
QUARTZ SAND
CHERT

STRUCTURE
LAMINATED
ALGAL
IRREGULARLY MOTTLED
DOLOMITIC OOLITIC
SUB-BANDED DOLOMITED CALCITIC
BANDED CALCAREOUS DOLOMITIC
CALCAREOUS DOLOMITIC
INDURATED SILTY BASINS
STYLOLITE

FOSSILS
Tetradella cf. T. pennsylvanica
Diparelasma cf. D. dicyanoides
Streptelasma sp.
Opikella cf. O. sella
Hapsiphora cf. H. gracilicos
Tryplasma cf. T. cerna
Coreteges rhombocornis
Coreteges subplana
Isochiletes sp.
Zethyrorella sp. E
Zethyrorella sp. B
Mystilloides sp. indet. 1
Mystilloides sp. indet. 2
Algal ? nonarticulate calcareous fossil

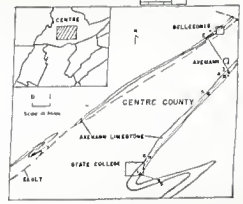


PLATE 13

THE AXEMANN LIMESTONE
STATE COLLEGE-WATERSIDE REGION

JOHN ALLEN LEES

SLAB CABIN CREEK-LITTLE JUNIATA RIVER

8 SLAB CABIN CREEK | 9 BAILEYVILLE | 10 GRAYSVILLE 1 | 11 GRAYSVILLE 2 | 12 GRAYSVILLE 3 | 13 EVERGREEN FARM | 14 SPRUCE CREEK | 15 LITTLE JUNIATA RIVER

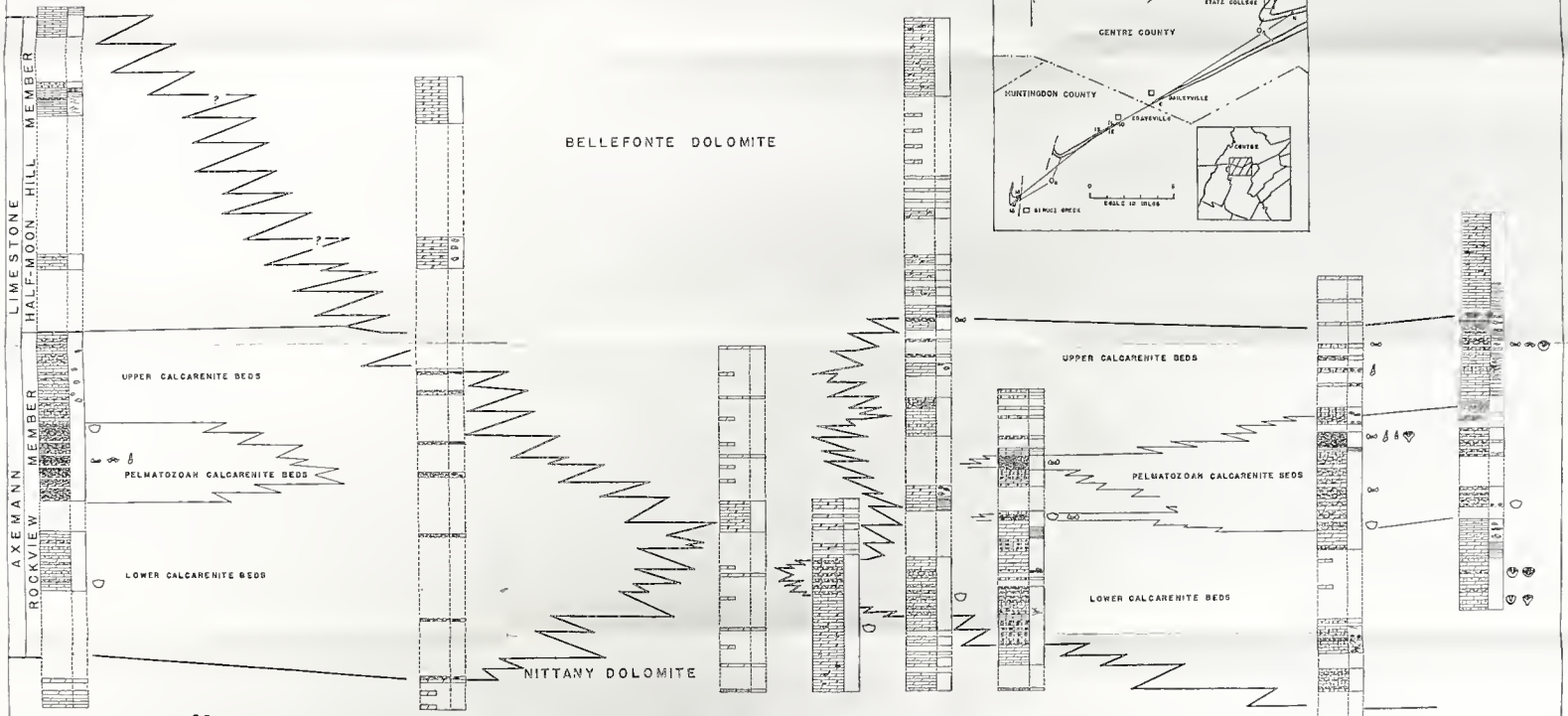


PLATE 14

THE AXEMANN LIMESTONE
STATE COLLEGE-WATERSIDE REGION

LITTLE JUNIATA RIVER-WATERSIDE

15	16	17	18	19	20	21	22	23
LITTLE JUNIATA RIVER	GOODMAN	MT ETNA	SPRING RUN	SHELLEYTOWN	BEAVERTOWN	CURRYVILLE	WOODBURY	WATERSIDE

BELLEFONTE DOLOMITE

AXEMANN LIMESTONE

NITTANY DOLOMITE

BELLEFONTE OOLOMITE

UPPER CALCARENITE BEDS

PELMATOZOAN CALCARENITE BEDS

LOWER CALCARENITE BEDS

NITTANY OOLOMITE

SCALE IN FEET 50 25 0

CONSOLIDATION AND TEXTURE

- DOLOSILTITE
- PELMATOZOAN CALCARENITE
- OOLITIC CALCARENITE
- LITHIC CALCARENITE
- FINE-GRAINED CALCARENITE
- CALCILUTITE
- FINELY CRYSTALLINE DOLOMITE
- MEDIUM- TO COARSELY CRYSTALLINE DOLOMITE
- DOLOMUDITE
- CHERT
- SURFACE BEDS
- FLOAT

STRUCTURE

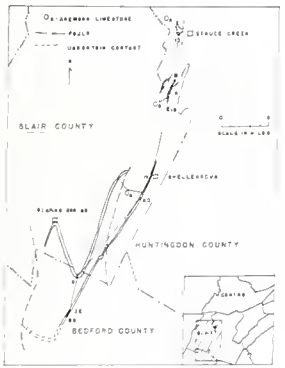
- LAMINATED
- WAVY-BEDDED CALCITIC DOLOMITE
- WAVY-BEDDED DOLOMITIC CALCITIC DOLOMITE
- IRREGULAR WAVY BEDS
- STYLOLITES

BEDDING

- LESS THAN 6 INCH BEDDED
- 6 INCH TO 4-FOOT BEDDED
- 4- TO 6-FOOT BEDDED

FOSSILS

- Tritaxis cf. T. pyramidata
- Tritaxis sp. indet.
- Dipnicalsema cf. D. gregarium
- Monotrypa sp.
- Ophiurida cf. O. sarda
- Holmesella cf. H. gracilipes
- Crinoidea cf. C. Solidi
- Isotelus sp.
- Bathyurellus sp.1
- Bathyurellus sp. 2



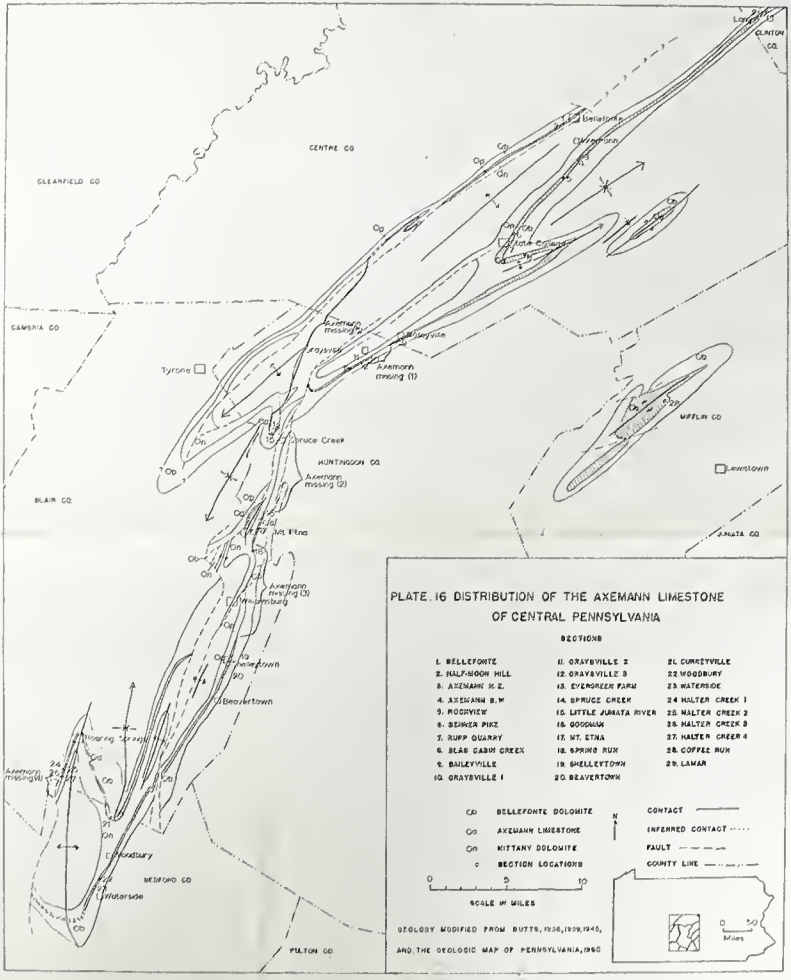


PLATE 16 DISTRIBUTION OF THE AXEMANN LIMESTONE OF CENTRAL PENNSYLVANIA

SECTIONS

1. BELLEFONTE	11. GRAYSVILLE 2	21. CUMRU VILLE
2. HALF-MOON HILL	12. GRAYSVILLE 3	22. WOODBURY
3. AXEMANN N.E.	13. EVERGREEN PARK	23. WATERSIDE
4. AXEMANN S.W.	14. SPRUCE CREEK	24. HALTER CREEK 1
5. MOORVIEW	15. LITTLE JUNIATA RIVER	25. HALTER CREEK 2
6. BEAVER PIKE	16. GOODMAN	26. HALTER CREEK 3
7. RUPP QUARRY	17. MT. ETNA	27. HALTER CREEK 4
8. BLAIR GAP CREEK	18. SPRING RUN	28. COFFEE RUN
9. BAILEYVILLE	19. SHELLEYTOWN	29. LAMAR
10. GRAYSVILLE 1	20. BEAVERTOWN	

Cb BELLEFONTE DOLOMITE
Ca AXEMANN LIMESTONE
On NITTANY DOLOMITE
○ SECTION LOCATIONS

CONTACT
INFERRED CONTACT
FAULT
COUNTY LINE

N

0 5 10
SCALE IN MILES

0 50
Miles

GEOLOGY MODIFIED FROM BUTTS, 1926, 1929, 1940, AND THE GEOLOGIC MAP OF PENNSYLVANIA, 1950

THE AXEMANN LIMESTONE

STATE COLLEGE-WATERSIDE REGION

HALTER CREEK SECTIONS

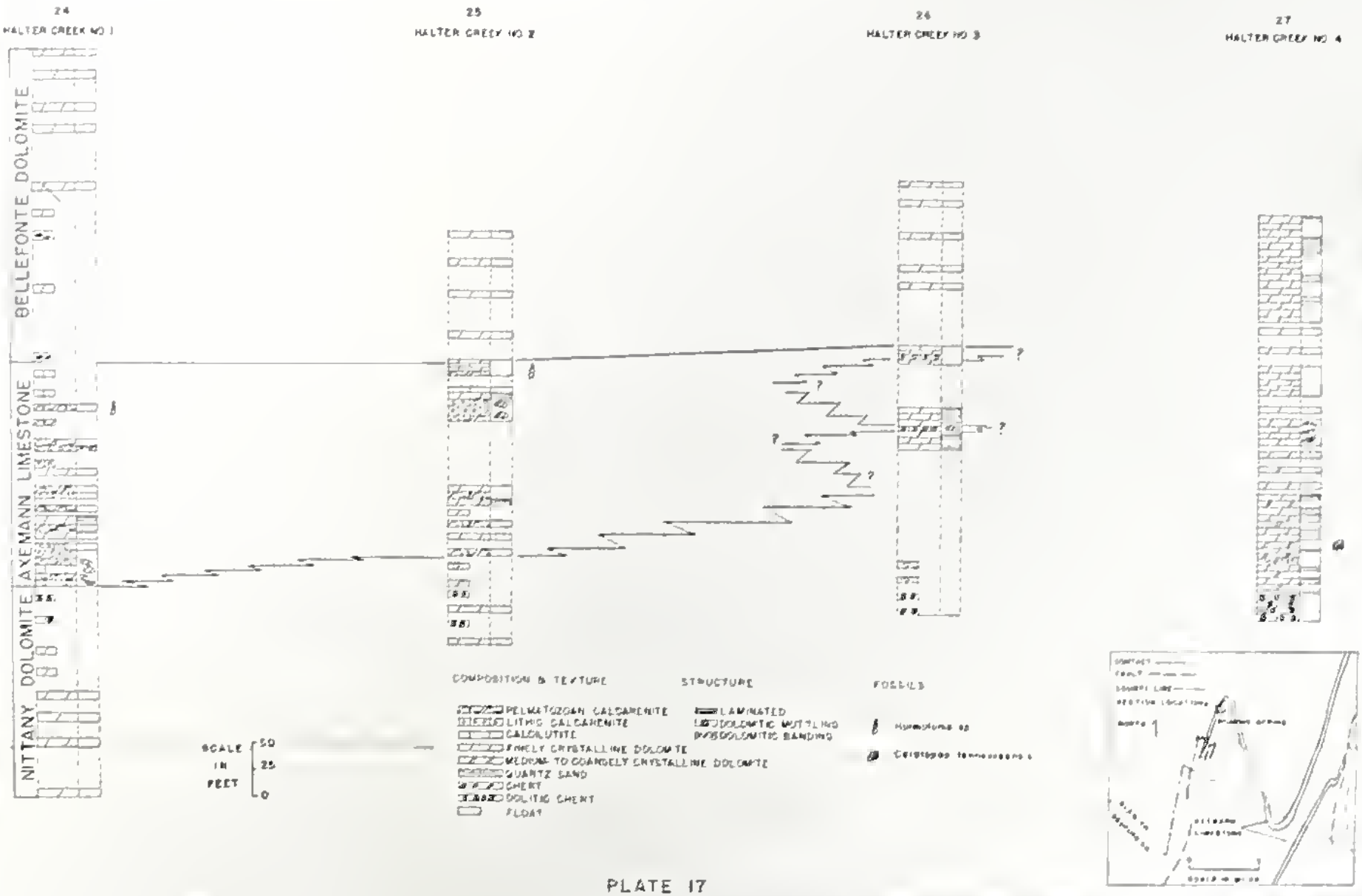


PLATE 17

THE AXEMANN LIMESTONE
LAMAR-AXEMANN-COFFEE RUN REGION

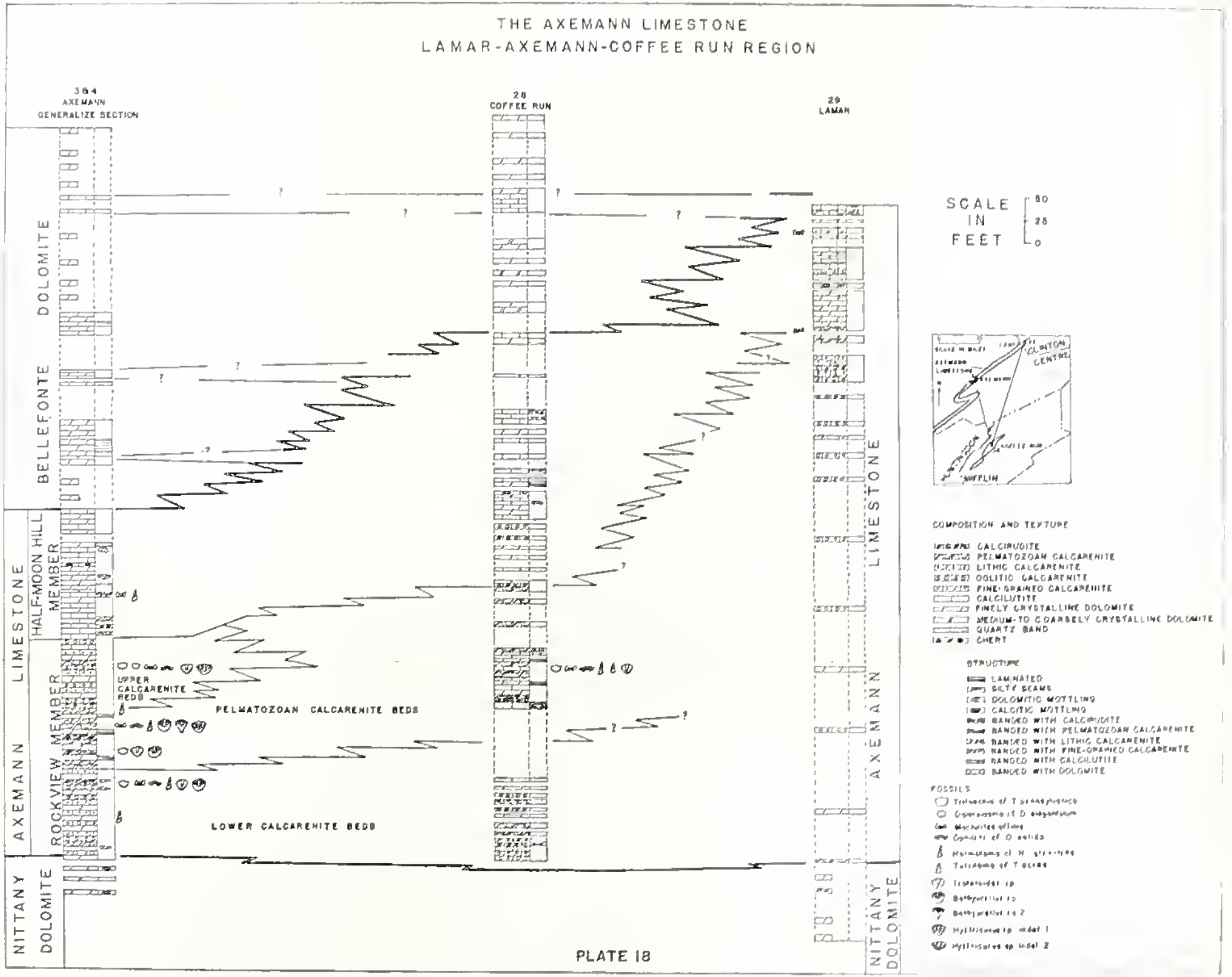
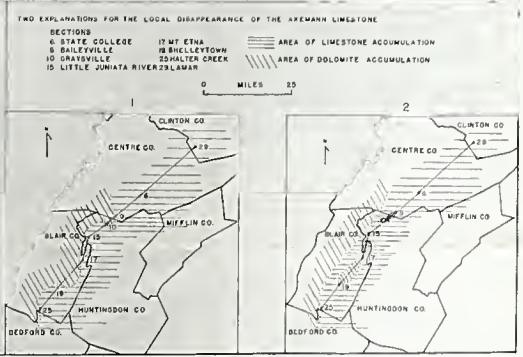


PLATE 18

PL. 19- GENERALIZED STRATIGRAPHY OF THE AXEMANN LIMESTONE FROM LAMAR TO HALTER CREEK (ROARING SPRING), AND TWO EXPLANATIONS FOR THE LOCAL DISAPPEARANCE OF THE AXEMANN LIMESTONE